SUSTAINABLE AND RESPONSIBLE AFTER-USE OF PEAT EXTRACTION AREAS

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FOREWORD

Nowadays, climate change and its impacts can no longer be ignored in planning of economic development and environmental management. Recently, we experienced a very dry year after a very wet summer. Predictions of climate change suggest that such extreme weather events will become more frequent, and this will introduce adjustments in agriculture, water management, environmental management and also the state budget. Therefore, throughout the world, including Latvia, the role of scientific studies and, above all, the role of action for climate change mitigation is increasing. The project of the EU LIFE programme “Sustainable and responsible management and re-use of degraded peatlands in Latvia” implemented by Nature Conservation Agency and partner organizations is the first project in Latvia under Climate Action sub-programme. For the first time in Latvia, with the involvement of scientists and practitioners, greenhouse gas emissions from peat extraction sites have been evaluated. Nature Conservation Agency has successfully implemented and continues the implementation of more than 20 nationally important projects in the field of biodiversity conservation. This project, dedicated to climate change mitigation, provides experience that is applicable for nature conservation and economic development.

During the project, the areas affected by peat extraction in Latvia were surveyed, and the information about degraded peatlands where reclamation is necessary was summarised. Research-based model of sustainable management of peatlands will help landowners to choose the most appropriate and cost-effective after-use of extracted peatlands. For the first time in the Baltic states, national greenhouse gas emission factors were determined. In the framework of the project, several reclamation types in extracted peatlands were tested. The experience gained was incorporated into reclamation recommendations.

Peatlands are of the greatest importance to economy, to the safety of society and even to the safety of urban environment. They act as giant sponges, reducing the risk of flooding and prolonged drought, providing us with clean groundwater, and providing a regulatory function in terms of ecosystem services. Therefore, not only conservation of natural mires, but also restoration of degraded peatland ecosystems is highly important.

The contribution of the LIFE REstore project is a solid foundation for mire and wetland owners to choose smart, cost-effective and environmentally friendly strategies to preserve the biodiversity and ecosystem services for our children and for generations to follow.

Juris Jātnieks

Director General of Nature Conservation Agency (Latvia)

GLOSSARY

Acrotelm – the upper layer of a mire, in which organic matter decomposes aerobically and much more rapidly than in the underlying, anaerobic catotelm.

Activity data – historical data regarding activities which cause anthropogenic greenhouse gas emissions or removal of carbon dioxide in a specific period of time (for instance, land use and peat extraction data).

After-use scenario – land use after peat extraction, e.g. forestry, agriculture, pond farming, recreation, biodiversity provision (nature conservation). The after-use scenario is determined by the landowner, coordinated with the relevant authorities and specified in the planning consent and license to operate. The after-use type can be determined also in the land lease contract.

Amelioration – see *Soil amelioration*.

Birds Directive – Directive 2009/147/EC of the European Parliament and of the Council of 30 November 2009 on the conservation of wild birds. The Directive therefore places great emphasis on the protection of habitats for endangered and migratory species. It establishes a network of Special Protection Areas (SPAs) including all the most suitable territories for these species. Since 1994, all SPAs are included in the Natura 2000 ecological network, set up under the Habitats Directive 92/43/EEC (see *Habitats Directive*).

Bog – see *Raised bog*.

Demo site – here – demonstration area within LIFE REstore project where certain reclamation methods (e.g. afforestation, establishment of cranberry plantations, etc.) were tested.

Donor area – place that serves as a source of collecting living parts of plants to be spread into other areas (reintroduced).

Carbon dioxide (CO_2) equivalent – greenhouse effect of different greenhouse gases in comparison to CO_2 (CO_2 eq.). CO_2 eq. of methane (CH_4) is 25 and CO_2 eq. of nitrous oxide (N_2O) is 298.

Emission factor – number characterizing linear correlation between activity data and greenhouse gas emissions (e.g. CO_2 emissions factor for organic soils in cropland with optional nutritional regime in temperate climate zone according to IPCC 2013 Wetlands supplement is 7.9 tonnes CO_2-C ha^{-1} year.).

Habitats Directive – the European Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora that aims to promote the maintenance of biodiversity, taking into account economic, social, cultural and regional requirements. It forms the cornerstone of Europe's nature conservation policy with the Birds Directive and establishes the EU wide Natura 2000 ecological network of protected areas, safeguards against potentially damaging developments.

Fen – a type of wetland that mainly receives nutrients from groundwater.

Greenhouse gases (GHG) – gaseous components of atmosphere of natural or anthropogenic origin which absorbs and reemits infrared radiation. In this book, GHG are considered according to the LULUCF regulation (carbon dioxide (CO_2), methan (CH_4) and nitrous oxide (N_2O)).

LULUCF Regulation – Regulation (EU) 2018/841 of the European Parliament and of the Council of 30 May 2018 on the inclusion of greenhouse gas emissions and removals from land use, land use change and forestry in the 2030 climate and energy framework, and amending Regulation (EU) No 525/2013 and Decision No 529/2013/EU.

Managed wetlands – land parcels which do not conform to criteria for forest land, cropland, grassland, settlements or other lands according to definitions applied in the guidelines by The Intergovernmental Panel on Climate Change (2006) and where management activities take place or which originated as a result of anthropogenic activities. The most common types of managed wetlands are artificial water bodies, including ponds, ditches and channels, peat extraction fields and constructed wetlands for wastewater or stormwater treatment.

Mire – a wetland type, dominated by living, peat-forming plants.

Myrtillosa turf. mel. – according to national classification of forest types in Latvia, forest type occurring on drained organic soils (fen and transition mire peat); the tree layer is dominated by Scots pine, Norway spruce or birch, or with birch in admixture.

Net greenhouse gas emissions – sum of greenhouse gas emissions and CO_2 removals. Emissions are usually expressed with a positive sign and CO_2 removals – with a negative sign, respectively negative net GHG emissions means that LULUCF sector or specific land use category is net sink contributing to reduction of GHG emissions and if net GHG emissions have a positive sign – the system is net source of GHG emissions contributing to increase of GHG in atmosphere.

Oxalidosa turf. mel. – according to national classification of forest types in Latvia, forest type occurring on drained organic soils (well decomposed wood and sedge peat); the tree layer is dominated by Norway spruce, common ash, black alder, birches and aspen, in admixture with birches, black alder and Scots pine.

Organic soils – according to IPCC 2006, soils are organic if they satisfy the requirements 1 and 2, or 1 and 3 below: (1) thickness of organic horizon greater than or equal to 10 cm. A horizon of less than 20 cm must have 12% or more organic carbon when mixed to a depth of 20 cm; (2) soils that are never saturated with water for more than a few days must contain more than 20% organic carbon by weight (i.e. about 35% organic matter); (3) soils are subject to water saturation episodes and has either: (a) at least 12% organic carbon by weight (i.e. about 20% organic matter) if the soil has no clay; or (b) at least 18% organic carbon by weight (i.e. about 30% organic matter) if the soil has 60% or more clay; or (c) an intermediate, proportional amount of organic carbon for intermediate amounts of clay.

Paludiculture – wet agriculture and forestry on peatlands. Paludiculture combines the reduction of greenhouse gas emissions from drained peatlands through rewetting with continued land use and biomass production under wet conditions.

Peat – a heterogeneous mixture of more or less decomposed plant (humus) material that has accumulated in a water-saturated environment and in the absence of oxygen.

Peatland – an area with or without vegetation with a naturally accumulated peat layer at the surface.

Production field – 20 m wide stretch in the peat extraction area, on both sides bordering with drains that ensure the necessary moisture conditions and the carrying capacity for machinery used in peat extraction.

Raised bog – a rain-fed (ombrotrophic) peatland type dominated by sphagnum mosses as the main peat forming plants. The raised bogs develop from fens and transition mires and are considered as the climax stage of succession. Raised bogs are usually dome-shaped with one or more cupolas.

Reclamation – a complex of measures that must be implemented to prepare the land after mining for further use, at the same time stabilizing slopes, assuring public safety, implementing aesthetic improvement, involvement in the surrounding landscape, i.e. returning the land to what is considered to be a useful purpose. Most commonly reclamation involves measures that lead to the after-use scenarios, such as forestry, agriculture, pond farming, berry plantations, paludicultures, recreation, biodiversity restoration. In the national legislation in Latvia, this is called *rekultivācija*.

Reclamation design – after-use plan; a document that defines the purpose of further land use after peat extraction and includes technical details for creation of certain land use type. According to national legislation, reclamation design must be in compliance with the municipal authorities.

Rehabilitation – here – a type of reclamation that focuses on recreating historical or pre-existing ecosystems and aims at repairing ecosystem processes, the pre-existing biotic integrity in terms of species composition and community structure and ecosystem services. In the national legislation in Latvia, this is called *renaturalizācija*.

Reintroduction – here – restoration of the populations of native (locally) extinct or nearly extinct species.

Soil amelioration – modifying soil to improve its quality; improving physical and chemical properties of soil.

Sphagnosa – according to national classification of forest types in Latvia, forest type occurring on water-logged organic soils that are acidic, composed of bog peat; the tree layer is dominated by Scots pine, with admixture of birches.

Transition mire – a type of minerotrophic (groundwater-fed) mire, where the impact of the groundwater recedes, but the role of precipitation increases. In transition mires, both species from fens and bogs may be found.

Wetland – an area that is flooded or saturated by water at a frequency and for a duration sufficient to support a prevalence of vegetation typically adapted for life in saturated soil conditions.

ABBREVIATIONS

cal. yrs. PB – calibrated years before the present

EC – European Commission

eq. – equivalent

ETS – emission trading system

EU – European Union

GHG – greenhouse gas

IPCC – The Intergovernmental Panel on Climate Change

LEGMC – Latvian Environment, Geology and Meteorology Centre

LULUCF – land use, land use change and forestry sector in the greenhouse gas inventory, where emissions and carbon dioxide (CO_2) removals in forest land, cropland, grassland, settlements, managed wetlands and other lands, including greenhouse gas emissions due to peat extraction for horticulture use

LSFRI Silava – Latvian State Forest Research Institute "Silava"

NFI – National Forest Inventory

non-ETS – sectors not included in emission trading system.

UN – United Nations

1. LIFE RESTORE PROJECT, ITS OBJECTIVES AND MAIN RESULTS

Ieva Bukovska, Ieva Saleniece, Anda Zālmane

Summary

The project "Sustainable and responsible management and re-use of degraded peatlands in Latvia" (LIFE14 CCM/LV/001103, LIFE REstore) within European Union's LIFE Climate Action programme was implemented from September 1, 2015 until August 30, 2019 by Nature Conservation Agency in partnership with Latvian Peat Association, Latvian State Forest Research Institute "Silava", and Association "Baltic Coasts".

Significant contributions were made within the LIFE REstore project: the developed national greenhouse gas emission factors for raised bog and transition mire peat soils and agricultural peat soils, as well as the approved method for measuring greenhouse gas emissions which will be an important component of the climate policy in Latvia.

The key project results are the decision-making tool for planning of responsible use of degraded peatlands after peat extraction, economic evaluation of ecosystem services in demo sites, and inventory of degraded peatlands affected by peat extraction that has resulted in an open-access database. The recommendations prepared by the project team on reclamation will be an important component in the National Peat Strategy.

Other contributions by the LIFE REstore project includes reclamation measures implemented in four degraded peatlands affected by peat extraction (demo sites): reintroduction of *Sphagnum* mosses, establishment of highbush blueberry and large cranberry plantations, afforestation, and rewetting a drained raised bog neighbouring with peat extraction area.

Until now, no studies on greenhouse gas (GHG) emissions from organic soils of various land use types had been carried out in Latvia, which would be based on GHG emission measurements in peatlands. Thus, national emission factors were not developed for managed wetlands, as well as for part of organic soils in agricultural and forest lands. Also, evaluation of efficiency of various reclamation measures in extracted peatlands for mitigation of global climate change was missing. So far, the information on extracted peatlands in Latvia was not summarised, including areas where peat extraction was completed or ceased, but where no reclamation measures had been implemented. There was no mechanism for decision making about sustainable management of these areas after peat extraction. Not all locations of these degraded areas were known, neither were their condition, properties of residual peat, and other characteristic features important for selecting the most appropriate reclamation method.

The project "Sustainable and responsible management and re-use of degraded peatlands in Latvia" (LIFE14 CCM/LV/001103, LIFE REstore) is the first climate change mitigation project in Latvia which was financed by the European Union LIFE Programme. LIFE REstore project was implemented from September 1, 2015 until August 30, 2019 by Nature Conservation Agency in partnership with Latvian Peat Association, Latvian State Forest Research Institute "Silava", and the association "Baltic Coasts". The project was fulfilled using the funding of LIFE Programme and Administration of Latvian Environmental Protection Fund.

The main objective of LIFE REstore project was to develop recommendations for sustainable management of areas affected by peat extraction in Latvia. The following tasks were set in order to achieve this objective:

- ✔ development of national emission factors and approbation of emission recording methodology based on analysis of GHG samples collected in field;
- ✔ vegetation inventory and geological survey in areas affected by peat extraction in Latvia;
- ✔ development of a decision-making tool for planning of a responsible use of areas affected by

peat extraction, which would ensure a balance between biodiversity conservation, economic benefits, and reduction of GHG emissions in Latvia in long term;

- ✔ support to policy makers by providing information, recommendations and methods for the sustainable use of areas affected by peat extraction.

Considerable research work has been carried out during the LIFE REstore project to improve the GHG emission factors from managed organic soils in order to replace the emission factors offered by Guidelines for GHG Inventories of Intergovernmental Panel on Climate Change (IPCC) with scientifically tested nationally applicable emission factors and activity data. The GHG emission accounting methods were adopted, based on two years of GHG emission measurements in lands with various land use types, in 41 sites in Latvia. National emission factors were developed for managed wetlands, as well as for a part of organic soils in agricultural and forest areas. To introduce the developed national factors, they will have to be published in scientific periodicals and presented during the International Auditing of National Inventory of GHG emissions. Latvia is the first among the Baltic states where the abovementioned national GHG emission factors have been developed.

Among the reclamation measures for cutaway peatlands tested within LIFE REstore project, the lowest net GHG emissions were found in large cranberry plantations and Scots pine plantations. Transformation of cutaway peatlands into agricultural lands was considered as an inappropriate after-use scenario, because it resulted in multifold increase of emissions from the soil. The studies done by LIFE REstore project team will be an essential component of planning and implementation of climate policy in Latvia, including achieving EU-LULUCF Regulation[1] objectives. This Regulation includes managed wetlands in the GHG reduction objectives from 2026 onwards. More on GHG measurements and their results within LIFE REstore project – see Chapter 3.

Within the LIFE REstore project, identification of peatlands affected by peat extraction was carried out. In order to prepare recommendations for sustainable management of these peatlands, their location, area size and condition had to be clarified. In total, ca. 50 thousand hectares of areas affected by peat extraction were identified. Out of them, ca. 15 thousand hectares (30%) are active peat extraction areas; ca. 17 thousand hectares (34%) are areas where reclamation measures have been or are currently being implemented; ca. 18 thousand hectares (36%) are abandoned cutaway peatlands where reclamation should be carried out. However, since in many of them there are unused peat resources left, first the peat could be harvested and then rehabilitation measures should be applied as required by the national regulations.

Data on peatland areas show the situation on January 1, 2016. About 18 thousand hectares of cutaway peatlands identified within the project are areas where peat extraction has been ceased or completed, but no reclamation has been carried out and no license for the use of peat resources is valid any longer. Seventy eight peatland areas (total area ca. 10 thousand hectares) were surveyed on site. Here, thickness of the residual peat layer was determined, as well as peat type at the upper layer, peat decomposition degree and pH value. Photographs and peat samples were taken in all surveyed sites.

Vegetation was surveyed in 32 cutaway peatlands with total area more than 32 thousand hectares. In these surveyed peatlands, peat extraction has been ceased at various periods, both ca. 60–70 years ago and recently. Also, the thickness of the residual peat layer, water table and degree of vegetation development were different. The results of this inventory show that vegetation development after cessation of peat extraction is primary influenced by moisture conditions. Development of mire vegetation is a prerequisite for peat accumulation. More about the vegetation inventory results – see Chapter 4.4.

1 Regulation (EU) 2018/841 of the European Parliament and of the Council of 30 May 2018 on the inclusion of greenhouse gas emissions and removals from land use, land use change and forestry in the 2030 climate and energy framework, and amending Regulation (EU) No 525/2013 and Decision No 529/2013/EU

Summary of peatland inventory was used for developing database on areas affected by peat extraction. It is an open access GIS-based database and functions as part of the Latvian Nature Data Management System OZOLS: https://restore.daba.gov.lv/public/lat/datu_baze1/ (see Chapter 4.5). For visualization of data layers and information analysis, two applications and story map were developed. In the geodatabase, spatial data and information that characterises the surveyed areas are available. Information about 237 territories affected by peat extraction is available, including 78 peatlands where geological surveys were carried out (301 peat cores analysed and other data) (see Chapter 4.2); 127 vegetation data forms from 32 peatlands; soil data from GHG measurement sites, and other information.

LIFE REstore project has tested five peatland after-use scenarios in four demo sites, as well as rewetting in a raised bog neighbouring to peat extraction site. In the cutaway peatland in Ķemeri Mire, *Sphagnum* mosses and other raised bog plants were reintroduced. In Kaigu Mire demo site, tree plantings and highbush blueberry *Vaccinium corymbosum* plantations were established. In Kaudzīšu Mire, large cranberries *Vaccinium macrocarpon* were planted. In Lauga Mire, a raised bog neighbouring to peat extraction area, ditches were blocked by peat dams, according to management measures recommended in the nature protection plan developed within the LIFE REstore project (see Chapter 6.3.4).

In the Ķemeri Mire demo site, more than 2200 kg of *Sphagnum* mosses were spread across an area of 4500 m^2. So far, this is the largest experiment of *Sphagnum* reintroduction in Latvia. Prior to planting, the site was prepared by removing the upper layer of highly decomposed peat. In four experimental plots, four *Sphagnum* species were planted in various combinations. The selected species, *Sphagnum rubellum*, *S. fuscum*, and *S. magellanicum* typically grow on raised bog hummocks, whereas *S. cuspidatum* is a hollow species (see Chapter 6.3.3). Vegetation dynamics in the *Sphagnum* reintroduction plots and in the neighbouring reference area is being monitored that allows observing and comparing vegetation development with and without the targeted mire rehabilitation measures.

During the LIFE REstore project, a nature protection plan for Lauga Mire Nature Reserve was developed and approved. The plan was developed in accordance with requirements set in the national legislation, and it defines the management objectives for the territory of nature reserve. In the 1960s, the water level of Lake Višezers was lowered by 1.3 m after establishment of a drainage system and initiation of peat extraction. Thus, the quality of Lake Višezers and the surrounding raised bog habitats was adversely affected by drainage. Nature protection plan includes measures for raising and stabilising the water level in Lake Višezers. Implementation of these measures ensures recovery of raised bog ecosystem in an area of 97.2 hectares. Thus, peat dams on drainage ditches were constructed to block the rapid water runoff from the bog. Nature protection plan developed within the LIFE REstore project is the first nature protection plan in Latvia that includes economic assessment of ecosystem services (see Chapter 5).

In Kaigu Mire demo site, in cooperation with SIA "Laflora", reclamation of the cutaway peatland was implemented by establishing a short rotation tree plantation to produce wood biomass. In an area of 9 ha, various tree species were planted in different combinations and using different fertiliser doses. In the other project demo site in Kaigu Mire, highbush blueberry plantations were established in an area of 4.2 ha, in cooperation with SIA "Arosa-R". In Kaudzīšu Mire demo site, a plantation of large cranberries was established. In cooperation with SIA "Kaudžu purvs", 6.3 t of cranberry shoots were planted in 3.4 ha of extracted peatland.

The aim of the LIFE REstore project was to reduce emissions by 2227 t CO_2 eq. per year, by implementing reclamation measures in the demo sites. This includes also the planned CO_2 removals of 838 t per year. According to default emission factors[2], implementation of planned reclamation measures in project demo sites will result in total annual GHG emission reduction by 4581 t CO_2 per year. The

2 Default emission factors – values of emission factors according to the 2006 guidelines of The Intergovernmental Panel on Climate Change (IPCC) for National Greenhouse Gas Inventories and 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands.

largest reduction of GHG emissions per area unit is ensured by afforestation. However, since rewetting results in a near-natural functioning ecosystem without anthropogenic GHG emissions, it is assumed that in long term also rewetting ensures a significant reduction of GHG emissions.

An economic assessment of ecosystem services provided by after-use scenarios implemented in the demo sites and adjacent areas was carried out. Ecosystem services were evaluated both for the initial situation and for five, 25 and 50 year periods. The economic assessment of ecosystem services was based on biophysical assessment and data on habitat types and cover (see Chapter 5).

A management optimization model for sustainable use of peatlands was developed within the project. It is a decision-making tool for planning the management and sustainable use of areas affected by peat extraction (see Chapter 6.4 and https://restore.daba.gov.lv/public/lat/optimizacijas_modelis1/). Using this support tool, state and municipal land managers, as well as private land owners, can choose the most appropriate and cost-effective way of peatland after-use, taking into account a contribution to climate change mitigation and an assessment of ecosystem services.

The recommendations for the implementation of reclamation measures which are mentioned in legislation are valuable contribution and an addition to the abovementioned optimization model. These recommendations are an important component for the future policy planning document "Guidelines for the Sustainable Use of Peat 2019–2030" (National Peat Strategy). When preparing the recommendations, both practical experiences of the implementation of reclamation measures in the project demo sites and expert recommendations were taken into account.

For a successful implementation of the project results, awareness and improved knowledge among stakeholders is essential. The project communication activities were focused on raising awareness on the importance of peatland ecosystem services and their monetary value; on the potential of peatlands for the climate change mitigation; on the integration of this knowledge into planning and decision-making for degraded peatlands. The target audiences were ministries and public authorities involved in fields related to peat extraction, owners and managers of peat extraction areas, municipalities with large areas of degraded peatlands, non-governmental organizations interested in peatland use and conservation, research and educational institutions, students, people living in the vicinity of the demo sites. An extensive work with national and regional media took place in order to raise the public awareness on sustainable management of peatlands in Latvian society in general.

The project team prepared various informative materials: publications in media, scientific papers, e-newsletters on topics and activities of the project, such as after-use scenarios of cutaway peatlands, GHG measurements, development of national GHG emission factors, and inventory of cutaway peatlands in Latvia. Ten documentary short films about the most significant project results were created.

An important part of the communication activities were educational and informative events – seminars, meetings with target groups, presentation of the project results in annual events which are important for peat industry, such as Baltic Peat Producers Forums, and guest lectures at universities.

Conclusions

By implementing rehabilitation measures in the project demo sites, the project has reached the stated climate change mitigation indicators. Among the tested options, establishment of large cranberry plantations and Scots pine plantations were considered the most efficient after-use scenarios for climate change mitigation. Transformation of extracted peatlands into agricultural lands can be considered as an inappropriate after-use scenario from the perspective of climate change mitigation.

During the project, proposals were prepared for implementation of environmental policy and climate goals in the European Union and Latvia. The national emission factors for organic soils, as well as the approved GHG emission measurement methodology developed by the project team will be an essential component in planning and implementation of climate policy in Latvia, including achieving the objectives of EU-LULUCF Regulation adopted in 2018.

Approximately 50 thousand hectares of land were identified by the LIFE REstore project experts as peatlands which are degraded by peat extraction. Out of these, in about 18 thousand hectares, a decision on their further use must be taken: it means that either reclamation must be implemented as soon as possible, or first the peat resources could be used and then reclamation could be carried out. The peatland inventory and reclamation recommendations developed within this project are an important practical addition to the National Peat Strategy to be adopted.

The model for sustainable management of degraded peatlands will be an important support for landowners for planning sustainable management of the territory and choosing the most appropriate after-use scenario for peatlands.

During the project lifetime, the cooperation ties between the parties involved in peatland management were strengthened and, in some cases, also established. These interactions are important and must be supported also in the future. Collaboration among Nature Conservation Agency, experts and entrepreneurs in the peat sector, as well as the leading scientists in all parties involved, contributed to an in-depth understanding of the interaction among nature conservation, climate change and economic development.

2. LEGAL FRAMEWORK FOR CLIMATE POLICY

Ieva Saleniece, Ieva Līcīte, Andis Lazdiņš

Introduction

The legal framework for climate policy is a complex set of international, European Union (EU) and Latvian policy decisions and legislation that define climate policy goals and reporting and accounting obligations for different sectors concerning greenhouse gas (GHG) emissions and carbon dioxide removals.

This chapter sequentially sets out the international legal framework for climate policy: the United Nations (UN) Framework Convention on Climate Change[3] of 9 May 1992 (Climate Convention), the Kyoto Protocol to the Climate Convention (the Kyoto Protocol), and the Paris Agreement under the Climate Convention. An overview of the EU climate policy framework has been provided, highlighting Regulation 2018/841[4] of the European Parliament and of the Council of 30 May 2018 (LULUCF Regulation), as well as a brief overview of the Latvian regulatory framework for climate policy regarding management of wetlands. The chapter highlights aspects of climate policy regulation that are important when looking at the wetland land management category aspects that characterize the specific situation in Latvia, for example, the proportion of GHG emissions of economic sectors outside the Emissions Trading Scheme (non-ETS). Information on the acquisition of activity data relevant to the implementation of climate policy, and the provisions for the calculation, reporting and accounting of GHG emissions are provided. Attention is drawn to the explanation that, according too Climate Convention, GHG emissions as a whole and in the sector are accounted only from managed wetlands, but not from natural wetlands. The same approach has been used in EU legislation on climate policy and thus also in Latvia.

Data on land use related GHG emissions and CO_2 removals are reported and accounted in the land use, land-use change and forestry sector (LULUCF). Wetlands is one of the six land categories in the LULUCF sector.

International legal framework

Climate Convention

Climate change is a global environmental problem, and therefore global solutions are needed, as defined in the guidelines at UN level. The Climate Convention is the basic document of the international climate policy. It is a framework and mechanism for global action on climate, and the first international law to combat climate change. The aim of the Climate Convention is to reduce GHG concentrations in the atmosphere to levels that prevent dangerous anthropogenic interference with climate processes.

In Article 1.2 of the Convention, climate change is defined as "[…] change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods".

According to Article 4.1(a) of the Climate Convention, Parties signatory to the Climate Convention shall establish "national inventories of anthropogenic emissions by sources and removals by sinks of all greenhouse gases." So the scope of the Climate Convention is anthropogenic GHG emissions and not natural climate change. It is important to remember this setting in discussions about climate targets in managed wetlands.

3 United Nations Framework Convention on Climate Change, 9 May 1992 (Climate Convention), https://unfccc.int/sites/default/files/conveng.pdf.

4 Regulation (EU) 2018/841 of the European Parliament and of the Council of 30 May 2018 on the inclusion of greenhouse gas emissions and removals from land use, land use change and forestry in the 2030 climate and energy framework, and amending Regulation (EU) No 525/2013 and Decision No 529/2013/EU.

For GHG emission and CO_2 removals calculations necessary for the implementation of Climate Convention, a common, internationally approved methodology is used, developed by the Intergovernmental Panel on Climate Change (IPCC). National GHG inventory (hereinafter – GHG inventory) is prepared to assess global and national individual performance towards climate targets in accordance with the IPCC guidelines.

The IPCC guidelines are regularly reviewed and updated, and a new refinement of the IPCC guidelines is expected in 2019. At present, GHG inventory is being prepared in accordance with the 2006 IPCC Guidelines for National GHG Inventories (hereinafter – IPCC 2006 Guidelines (IPCC 2006)) and 2013 Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol. In the calculation of GHG emissions and CO_2 removals from wetland management, the 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: "Wetlands" (hereinafter – IPCC Guidelines 2013) is used (IPCC 2014).

Given that national data are often not available, and national GHG emission calculation factors have not been yet developed, the IPCC guidelines offer regional default data for calculating GHG emissions and CO_2 removals, but at the same time calls on countries to move towards national activity data and towards obtaining and using national GHG emission factors which significantly improves the accuracy of calculations and describes the country's specific circumstances. For example, up to 2017, IPCC data were used in Latvian GHG inventory reports for the characterization of areas used for peat extraction, but in 2018, GHG inventory report included information obtained in a result of the implementation of the LIFE REstore project. Similar improvements are also planned for the development of national GHG emission factors.

The Kyoto Protocol

For the implementation of the Climate Convention, the Kyoto Protocol was adopted in 1997, setting targets for GHG emission reduction for developed countries from 2008 to 2012. Latvia has achieved its target for the first period of the Kyoto Protocol – to reduce GHG emissions by 8% compared to 1990. In 2012, GHG emissions were 58% lower than emissions in 1990[5]. Part of the reduction was due to the restructuring of the economy through the transition to market economy. Also the modernization of the energy sector, the increase in the use of wood and natural gas and investment in modernization of production should be noted. Latvia has actively used the flexible mechanisms developed under the international climate policy. It should be noted that Latvia was the first in the world to create a "green investment system" (Prūse 2016)[6].

After the end of the first commitment period, the Kyoto Protocol was extended from 2013 to 2020 (the second commitment period of the Kyoto Protocol). After 2020, the approach of the second commitment period of the Kyoto Protocol will be replaced by the commitments under the Paris Agreement on Climate Change.

In the LULUCF sector, GHG emissions and CO_2 removals are reported in six categories of land – forest land, cropland, grassland, wetlands, settlements and other land, as well as for land use change – afforestation and deforestation. In the GHG inventory, the LULUCF sector differs from other sectors by including not only GHG emissions but also CO_2 removals, and by the fact that during different commitment periods LULUCF sector's land use categories and activities are included in the accounting against the GHG emission reduction targets differently.

Under the Convention, GHG inventory reports each year on GHG emissions and CO_2 removals for all

5 National GHG inventories in 2014, https://unfccc.int/process/transparency-and-reporting/reporting-and-review-under-the-convention/greenhouse-gas-inventories/submissions-of-annual-greenhouse-gas-inventories-for-2017/submissions-of-annual-ghg-inventories-2014.

6 Financial Instrument for Climate Change, established by the Law "On Participation of the Republic of Latvia in the Flexible Mechanisms of the Kyoto Protocol".

LULUCF land categories. At the same time there is a different approach to reporting GHG emissions and CO_2 removals in relation to GHG emission reduction targets under the Kyoto Protocol, respectively, there are activities to be accounted mandatory, while the inclusion of other activities in the accounts is voluntary. In both periods of the Kyoto Protocol, mandatory accounting includes forest management, afforestation and deforestation, but countries have been given a choice on how to include other activities, including wetland management. Latvia has not chosen to supplement mandatory accounting activities with the voluntary accounting of other activities during the Kyoto Protocol periods. However, EU countries, including Latvia, are currently working on the development of accounting systems for GHG emissions and CO_2 removals resulted by management of croplands and grasslands, in order to include the management of croplands and grasslands in mandatory accounting after 2020, in line with the EU legal framework[7].

Accounting for GHG emissions and CO_2 removals in managed wetlands is not mandatory in Kyoto commitment periods, and Latvia has not selected volunteer accounting for this type of LULUCF activity.

Paris Agreement

The post-2020 international climate change regulatory framework is based on the Paris Agreement adopted under the Climate Convention, which was approved on 12 December 2015 by unanimous decision of 195 UN countries. The overarching objective of the Paris Agreement is to keep the global average temperature rise well below the 2° C threshold compared to pre-industrial levels, and strive for to temperature increase limitation to 1.5° C. In addition to the GHG emission reduction targets, the Paris Agreement also sets targets related to adaptation to climate change and investment diversion to low carbon development after 2020.

The Paris Agreement will replace the Kyoto Protocol after its expiry in 2020. Unlike the Kyoto Protocol, which set GHG reduction targets only for developed countries, the Paris Agreement requires all countries to commit to GHG reduction (developed and developing countries). The joint commitment of the EU Member States is to reduce GHG emissions by at least 40% by the year 2030 compared to 1990, and by 80–95% by the year 2050 compared to 1990 levels. Towards these long-term goals, the EU is developing a framework for regulatory and strategic document regulation (Delbeke, Vis (eds.) 2015).

EU long-term climate policy goals

Within the framework of the Paris Agreement, the EU (including Latvia) needs to develop and, by the year 2020, submit a long-term low greenhouse gas emission development strategy[8] to the UN Climate Change Secretariat. On 28 November 2018, the European Commission (hereinafter – EC) published a statement entitled "A Clean Planet for All! A strategic long-term vision for a prosperous, modern, competitive and climate-neutral economy by 2050", calling for a climate-neutral economy by 2050[9].

Under the Climate Convention (Kyoto Protocol and Paris Agreement), GHG reduction targets are set compared to 1990 levels. For further international commitments, the EU accordingly adopts an EU-wide legal framework setting out the total amount of EU commitments, Member State commitments and enforcement rules. The 2020 and 2030 EU GHG targets are 20% and 40% respectively compared to

7 Decision No 529/2013/EU (21 May 2013) on accounting rules on greenhouse gas emissions and removals resulting from activities relating to land use, land-use change and forestry and on information concerning actions relating to those activities.

8 Paris Agreement, Article 4.19 and Decision 1/CP.21 35.

9 A Clean Planet for all! A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy https://ec.europa.eu/clima/sites/clima/files/docs/pages/com_2018_733_en.pdf.

1990. If the Kyoto Protocol sets a GHG reduction commitment compared to 1990[10], then the EU-level regulatory framework "translates" the reduction targets into national commitments compared to emissions of 2005.

The overall EU GHG reduction targets for their implementation are divided into two parts – the activities included in the EU Emissions Trading Scheme (ETS) and those not included in the EU ETS (hereinafter – non-ETS). ETS is the most important tool to help reduce GHG emissions in certain industrial and energy companies, and it is their responsibility to reduce emissions. The non-ETS GHG reduction target is in turn redistributed to each EU Member State, setting the legal framework for this redistribution for the period 2013–2020[11] and 2021–2030[12], respectively. Non-ETS activities include: energy, transport, agriculture, waste management, and industrial processes not included in ETS.

Over the period 2013–2020, the meeting targets of the LULUCF sector, including category of wetlands, is not related to the non-ETS sector's GHG emission reduction target. In contrast, after 2020, or in 2021–2030, the LULUCF sector's goal and its target accounting is related to achieving non-ETS goals. The EU regulatory framework makes this linkage so that, in the event of non-fulfillment of LULUCF's objectives, underachievement must be covered by the non-ETS sector, and opposite, non-ETS non-compliance can be compensated by the particular amount of GHG emission units that are generated in the excess quantity in the LULUCF target accounting.

Latvian Climate Commitment and EU Climate Policy Legislation

The structure of the Latvian economy determines that GHG emissions from the Latvian non-ETS sector account for a very high proportion, accounting for almost 81% of the total GHG emissions of the country. Such a proportion of non-ETS sector GHG emissions is the second highest among EU Member States (Luxembourg is highest)[13]. According to 2016 data[14], the EU average of non-ETS emissions is 60%. The high proportion of the non-ETS sector illustrates the topicality of this sector in the context of Latvia's climate policy. Analyzing the structure of the non-ETS sector in Latvia, it can be seen that the largest amount of GHG emissions is constituted by the transport sector (28% of total emissions), and the agricultural sector (24% of total emissions, respectively)[15].

For each period of climate policy regulation, by redistributing common EU objectives, different national targets are set for Latvian non-ETS sector. Between 2013 and 2020, Latvia has a target that limits GHG emission growth to 17% compared to 2005. However, in the period from 2021 to 2030, the target for Latvia's non-ETS GHG reduction is stricter, and it is necessary to ensure a 6% reduction in GHG emissions compared to the 2005 GHG emissions in this sector. The overall targets for each period are also divided into annual binding targets.

The LULUCF sector targets for the period up to 2020 are not included in EU level commitments, but in the individual international commitments of those countries that have ratified the Climate Convention

10 Kyoto Protocol base year data (for the second commitment period of the Kyoto Protocol), https://unfccc.int/process/transparency-and-reporting/reporting-and-review-under-the-kyoto-protocol/second-commitment-period/kyoto-protocol-base-year-data-for-the-second-commitment-period-of-the-kyoto-protocol.

11 Decision No 406/2009/EC of the European Parliament and of the Council of 23 April 2009 on the effort of Member States to reduce their greenhouse gas emissions to meet the Community's greenhouse gas emission reduction commitments up to 2020.

12 Regulation (EU) 2018/842 of the European Parliament and of the Council of 30 May 2018 on binding annual greenhouse gas emission reductions by Member States from 2021 to 2030 contributing to climate action to meet commitments under the Paris Agreement and amending Regulation (EU) No 525/2013.

13 NECP 2030, Table 12. Share of GHG emissions from non-ETS activities in Latvia and differences in 2016 (%). National Energy and Climate Plan for Latvia 2021–2030. Draft for submitting to the European Commission for evaluation, https://ec.europa.eu/energy/sites/ener/files/documents/latvia_draftnecp_en.pdf .

14 Data viewer on greenhouse gas emissions and removals, sent by countries to UNFCCC and the EU Greenhouse Gas Monitoring Mechanism (EU Member States), https://www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer.

15 NECP 2030, Table 13. National Energy and Climate Plan for Latvia 2021–2030. Draft for submitting to the European Commission for evaluation. https://www.em.gov.lv/lv/nozares_politika/nacionalais_energetikas_un_klimata_plans/.

and its Kyoto Protocol (including Latvia), therefore no EU-level regulatory framework for LULUCF sector's GHG emissions and CO_2 removals have been developed for this period. The situation is different after 2020, when the EU has committed itself to include all economically active sectors, including the LULUCF sector, in the EU common GHG reduction target under the EU Paris Agreement, and accordingly has developed an EU-level regulatory framework[16] – the LULUCF Regulation 2018/841 – to meet these commitments at Member State level.

The obligations and the accounting rules for GHG emissions and CO_2 removals provided by LULUCF Regulation 2018/841 relate to six land accounting categories – afforested land, deforested land, managed cropland, managed grassland, managed forest land and, from 2026, also managed wetland. Within the meaning of the LULUCF Regulation 2018/841, managed wetland is land which, according to the declared use, is a wetland that does not change the status of wetland, or settlement or other land converted to wetland, or wetland converted to settlement or other land.

The LULUCF Regulation 2018/841 defines the overall objective of the LULUCF sector to ensure that in the accounting periods 2021–2025 and 2026–2030, the sum of accounted GHG emissions listed in the respective land accounting categories does not exceed the sum of accounted removals of the same categories.

So the implementing of LULUCF's target is divided into two stages: 2021–2025 and 2026–2030. This distinction is particularly relevant for the accounting of GHG emissions and CO_2 removals from managed wetlands, as the managed wetland category in the LULUCF target is mandatory only in the second phase – between 2026 and 2030. Considering that wetlands are efficient carbon storage systems, it is recognized that by protecting and restoring wetlands it is possible to reduce the overall GHG emissions of the LULUCF sector. The LULUCF Regulation 2018/841 sets out the accounting requirements for each LULUCF sector's land accounting category. For most land accounting categories (except for afforested land and deforested land), the accounting rules provide for "measuring" the fulfillment of targets against a certain time period or reference value. In the case of managed wetlands, this period is 2005–2009, which means that future GHG emissions are compared with historical GHG emissions of the period 2005–2009. If GHG emissions exceed historical emissions of the period 2005–2009, it is recorded as emissions. If emissions are lower than in the period 2005–2009, it is recorded as removals. Similarly, GHG emissions and removals in all other land accounting categories of the LULUCF sector are accounted thus allowing the assessment of the overall target achievement of the LULUCF sector at the end of the period – whether the balance of accounted GHG emissions and accounted CO_2 removals in all land accounting categories has been achieved. Where accountable emissions are recorded in one of the land accounting categories, they must, for the purposes of the target, be compensated for by counting removals in other land categories in order to obtain a zero or a "surplus" of the counting removal. If the accounted emissions are recorded in one of the land accounting categories, they must be compensated by the accounted removals in other land categories to fulfill the target to reach zero in the sum, or to "surplus" of the accounted removals. As mentioned above, the EU legal framework for the period 2021–2030 reciprocally links the fulfillment of the non-ETS and LULUCF sectoral targets. In the case of the overachievement of the LULUCF sector target, the surplus of accounted removals in a certain, limited amount can be used for the compensation for failure to meet targets (if it occurs) in the non-ETS sector[17],[18]. On the other hand, if the objective of the LULUCF sector is not met and there is a surplus of accounted emissions, it has to be compensated for by the non-ETS sector, which makes it more difficult

16 Regulation (EU) 2018/841 of the European Parliament and of the Council of 30 May 2018 on the inclusion of greenhouse gas emissions and removals from land use, land use change and forestry in the 2030 climate and energy framework.

17 Regulation (EU) 2018/842 of the European Parliament and of the Council of 30 May 2018 on binding annual greenhouse gas emission reductions by Member States from 2021 to 2030 contributing to climate action to meet commitments under the Paris Agreement and amending Regulation (EU) No 525/2013.

18 For Latvia, a maximum amount of 3.1 million tonnes of CO_2 equivalent is set under Article 7 (1) (a) and Annex III of the non-ETS Regulation 2018/842.

to meet the non-ETS sector target[19]. Linking these two sectoral objectives can contribute to or hinder the achievement of the common climate policy goals, and it makes the achievement of the LULUCF sector's objectives particularly relevant, including in relation to the inclusion of managed wetland land category from 2026 onwards.

The LULUCF Regulation 2018/841 makes a specific exception for the land accounting category of managed wetlands. In the mandatory accounting for the LULUCF target in 2021–2025, all land categories referred to in the LULUCF Regulation 2018/841 are included, except for the category of managed wetlands. The accounting of category of managed wetlands is not mandatory in the first phase of the LULUCF Regulation 2018/841 – it may be optional for Member States. In the second phase of the LULUCF Regulation 2018/841, in the period 2026–2030, however, the category of managed wetlands is included in the mandatory accounting. One of the reasons for the initial non-inclusion of managed wetlands in the inventory is the need to introduce the use of the 2013 IPCC Guidelines for calculating GHG emissions in all Member States, Article 2, Paragraph 4 of the LULUCF Regulation 2018/841 states that, where appropriate, in the light of experience gained in applying the IPCC in the IPCC guidelines, the European Commission may come forward with a proposal to postpone the mandatory accounting of managed wetlands for another five-year period.

Reporting and accounting rules for GHG emissions and CO_2 removals set by legislation of Latvia

Latvian legislative acts define the procedures for calculating GHG emissions and CO_2 removals in accordance with international and EU-level legal regulations for the preparation of various types of reports and for the accounting of climate change reduction targets. Law "On Pollution" and Cabinet Regulation No 737 "Regulations Regarding the Establishment and Maintenance of the National System for the Greenhouse Gas Inventories and Preparation of Projections" (hereinafter – Cabinet Regulation No 737) establish institutions (national system) and conditions for the calculation of annual and projected GHG emissions and CO_2 removals, and for reporting on the assessment of progress of the set objectives.

The national GHG inventory (prepared annually) is the main source of information on GHG emissions and CO_2 removals data in Latvia and is used to assess the progress of climate targets. The key elements of the GHG inventory report are:

- ✔ activity data (primary and secondary) – data on activities generating anthropogenic GHG emissions or CO_2 removals over a given period (including land use and peat extraction);
- ✔ GHG emission factors – values that determine the amount of GHG emissions or CO_2 removals per unit of activity.

An important element of GHG inventory is also information about the level of uncertainty of calculations, which is characterized by a lack of knowledge about the actual value of the variable parameter, which can be expressed as a probability proportion, which in turn characterizes the possible range and probability of the parameter value.

For calculating GHG emissions and CO_2 removals, Latvian institutional system for GHG inventory and projection reports has been established according to Cabinet Regulation No 737. Responsibility for the preparation of the calculations of GHG emissions and CO_2 removals of the LULUCF sector has been conferred to by the Latvian State Forest Research Institute "Silava" (hereinafter – LSFRI Silava). In turn, the following institutions are involved in the preparation of the data necessary for the calculation of GHG emissions and CO_2 removals of managed wetlands:

19 Regulation (EU) 2018/841 of the European Parliament and of the Council of 30 May 2018 on the inclusion of greenhouse gas emissions and removals from land use, land use change and forestry in the 2030 climate and energy framework.

1. The Latvian Environment, Geology and Meteorology Centre and the association "Latvian Peat Association" annually prepare and submit information to LSFRI Silava – about the areas where peat extraction has taken place, including geospatial data;
2. On annual basis, Central Statistical Bureau of Latvia prepares and submits data on peat extraction (extraction of all peat and of fuel peat), export, import, energy use (tons of dry matter);
3. The State Limited Liability Company "Real Estate of the Ministry of Agriculture" and the Joint Stock Company "Latvijas valsts meži" shall prepare and submit to LSFRI Silava an updated geospatial information on drainage systems, including on the building year and the latest year of reconstruction of drainage systems, closed drainage collectors and ditches.

LVMI Silava, in cooperation with the Ministry of Agriculture, prepares secondary data and GHG emission and CO_2 removals projections for LULUCF activities using National Forest Inventory data and data provided by other organizations as well as prepares GHG inventory and report sections on GHG projections, measures and policies, that include information on LULUCF sector, including GHG emissions and CO_2 removals caused by wetland management.

The national GHG emission factors developed in the LIFE REstore project are very important because they reflect the geographic and environmental condition of Latvia, which can not always be said about the GHG emission factors specified in the IPCC guidelines. IPCC default factors are prepared for large regions and can be used in cases if the state has not developed national emission factors for various reasons. Before the inclusion of nationally developed GHG emission factors into national GHG inventory calculations, any new, nationally developed GHG emission factor must be published in scientific periodicals; it must be clearly described and justified for its use in GHG inventory, and must be approved during the international audit of GHG inventory.

Finally, it should be emphasized once again that, according to the Climate Convention, GHG emissions in the LULUCF sector are accounted only from managed wetlands and not from natural wetlands. This approach has also been incorporated into the EU climate legislation. Thus, the often heard comparison between GHG emissions from managed wetlands and natural mires is not appropriate, either in terms of meeting commitment targets or in the GHG inventory reporting.

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3. LIFE RESTORE PROJECT CONTRIBUTION TO THE GREENHOUSE GAS EMISSION ACCOUNTS IN LATVIA

Andis Lazdiņš, Ainārs Lupiķis

3.1. Greenhouse gas measurements and their results in the LIFE REstore project

Summary

Within the scope of the LIFE REstore project for the first time in the Baltic states a study has been carried out for improvement of emission factors of greenhouse gases (carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O)) from managed organic soils, in order to replace the default emission factors set by the Intergovernmental Panel on Climate Change (further – IPCC) Guidelines for National Greenhouse Gas Inventories with scientifically proven emission factors, suitable for application in Latvia. Land use types included in the study are peat extraction sites, including areas, where peat extraction is abandoned and the areas that have not been re-cultivated, deciduous and coniferous forest stands on extracted peat fields, agricultural lands, including cropland, grassland, large cranberry and highbush blueberry plantations, as well as relatively intact parts of raised bogs and transition mires. In total, measurements have been carried out in 41 objects, and data from 36 sites have been used for elaboration of the emission factors. In parallel with the gas exchange measurements, a comprehensive characterization of soil and groundwater was done, determining those parameters, which can significantly influence GHG emissions from soil. The primary focus is on the factors that can be measured or modelled relatively easy, for example, groundwater table and the carbon-to-nitrogen ratio. In forest land carbon input in soil was determined from tree litter and living tree biomass.

It was concluded that in the 2013 supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Wetlands) the default coefficients of GHG inventory guidelines are about two times higher than the actual emissions.

Emission factors elaborated within the project characterize peat soils in raised bogs and transition mires as well as organic soils in cropland and grassland, where availability of nutrients has increased several times, compared to peat extraction fields, due to management activities. Taking this into consideration, it cannot be assumed that, when transforming a cropland on organic soil to grassland or a blueberry plantation, in the foreseeable future GHG emissions would decrease to the level of indicators specific to the objects of corresponding vegetation types included in the study.

Introduction

Soil is the largest carbon pool in terrestrial ecosystems (Liski et al., 1999; Davidson, Janssens, 2006), one third to one fifth of which comprises the carbon stock in organic soils (Post et al. 1982; Riutta 2008; Simola et al. 2012). According to the 2006 guidelines of The Intergovernmental Panel on Climate Change (hereinafter – IPCC) for National Greenhouse Gas (GHG) Inventories (hereinafter – 2006 IPCC guidelines, Eggleston et al. (eds.) 2006), soils are organic, if they meet the following criteria:

- ✔ Thickness of the organic matter-rich layer is at least 10 cm, soil is never saturated with water or saturated only a few days per year, the content of organic carbon in a mixed 20 cm thick soil layer is at least 12%, but in the organic matter-rich layer the content of organic carbon is at least 20% (the content of organic matter is at least 35%);
- ✔ Thickness of the organic matter-rich layer is at least 10 cm, soil is periodically or permanently saturated with water, in a mixed 20 cm thick soil layer the content of organic carbon is at least 12%, but in the organic matter-rich layer it is at least 12%, if soil does not contain clay particles (less than 0.002 mm in diameter) or at least 18%, if the content of clay particles in soil is 60% or the content of organic carbon corresponds with the regression line shown in Figure 1.

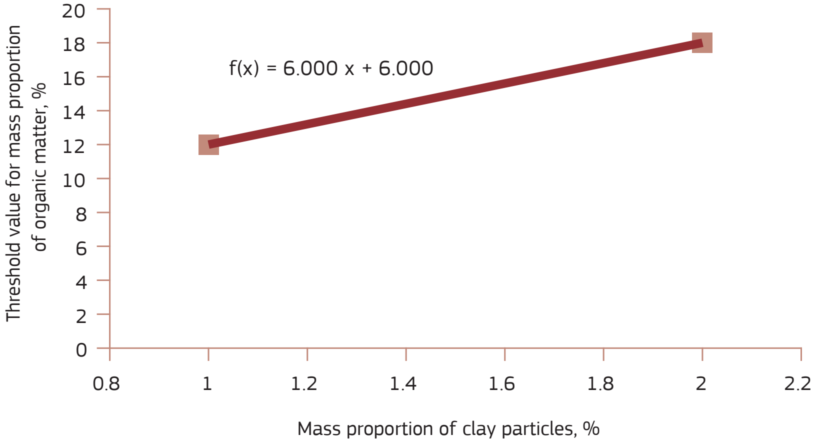

Figure 1. The limiting value of organic carbon in soils, which are periodically or permanently saturated with water, depending on clay particle content in soil parent material (Eggleston et al. (eds.) 2006).

The large carbon stock attaches great importance to organic soils in the context of climate change, because inappropriate management of these soils can cause additional CO_2 emissions, reinforcing the process of global warming. There are significant resources of organic soils in Latvia as well. Organic soils have a large impact on the level of GHG emissions in the Land Use, Land-Use Change and Forestry (LULUCF) sector, including GHG emissions and CO_2 removals from wetland, forest land, cropland, grassland and agricultural sector. In Latvia the primary source of CO_2 emissions is drained organic soils. More than half of these emissions are from forest land (818 thousand t CO_2 in 2016). Also GHG emissions caused by wetland management from soil is a relatively significant source – 345 thousand t CO_2 eq. in 2017, excluding emissions due to peat extraction. GHG emissions from wetland soils are gradually decreasing, because former peat extraction sites have gradually overgrown with trees. GHG emissions from these areas after afforestation are accounted in the category of forest land.

Organic soil drainage enhances decomposition of organic matter and organic soils often become significant sources of CO_2 emission (Pertti et al. 1995; von Arnold et al. 2005; Hirano et al. 2008; Hommeltberg et al. 2014; Jauhiainen et al. 2014). Also emission factors from drained organic soils included by the 2013 supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories – Wetlands (further – 2013 IPCC guidelines; Hiraishi et al. 2016) show significant carbon losses – emission factors range from 0.25 to 0.93 t CO_2-C ha^{-1} annually in boreal forests, 2.6 t CO_2-C ha^{-1} annually in temperate forests and 5.3 t CO_2-C ha^{-1} annually in tropical forests. Emission factors reflect the impact of climatic conditions on the decomposition rate of organic matter after drainage. Moving from higher to lower latitude, emissions decrease after drainage. It can be concluded that the emission factors included in the 2013 IPCC guidelines are not applicable for conditions in Latvia. Accordingly, for drained forests on organic soils the CO_2-C soil emission factor should be applied, which corresponds to temperate forests. The same emission factor should be used also in the western and southern parts of Europe, where climatic conditions differ significantly from Latvia. Also for peat extraction sites the same GHG emission factors are applied which correspond to the temperate climate zone. The summary of emission factors in the 2013 IPCC guidelines is given in Table 1. An exception is rewetted areas, including those areas, whose GHG emission factors are given in the 2006 IPCC guidelines.

Table 1. GHG emission factors according to the 2013 guidelines.

GHG	Nutrient supply	Unit	Forest	Cropland	Grassland	Rewetted organic soil	Peat extraction fields
CO_2	Poor	tonnes CO_2-C ha^{-1}	2.60	7.90	5.30	-0.23	2.80
	Good		2.60	7.90	6.10	0.50	2.80
DOC	Poor	tonnes C ha^{-1}	0.31	0.31	0.31	0.24	0.31
	Good		0.31	0.31	0.31	0.24	0.31
CH_4	Poor	kg CH_4 ha^{-1}	2.50	0.00	1.80	122.67	6.10
	Good		2.50	0.00	16.00	288	6.10
CH_4 from ditches	Poor		217	1165	1165	-	542
	Good		217	1165	1165	-	542
Share of ditch area	-	-	3%	5%	5%	-	5%
N_2O	Poor	kg N_2O-N ha^{-1}	2.8	13	4.3	-	0.3
	Good		2.8	13	8.2	-	0.3

The impact of forest drainage on climate change is not unambiguous. It cannot be concluded with certainty that drainage always causes an increase in GHG concentrations in the atmosphere and subsequently lead to global warming. Contrary to the general opinion that carbon stock in soil decreases after drainage, because of the increase of CO_2-C emissions, several authors imply that in certain cases carbon stock does not decrease, and in boreal forests can even increase (Lohila et al. 2011; Minkkinen, Laine 1998; Ojanen et al. 2013). Similar conclusions have been made in Latvia too, where an increase in carbon stock is observed after drainage and afforestation of a transition mire (Lupiķis, Lazdiņš 2015). These tendencies have not been observed in studies conducted in forests south from the boreal forest zone. However, there is not enough information about the transitional zone between boreal and nemoral forests, called the hemiboreal zone, in which Latvia is located. Studies on other land use types, including managed wetlands, cropland and grassland on organic soils in regions that correspond to the climatic conditions of Latvia are fragmentary and do not give a clear impression on the link between the emission factors given in the guidelines and the actual emissions from soil.

Whether soil in forest ecosystem becomes a net source or a sink of CO_2 emissions after drainage is determined by soil fertility, depth of drained layer and dominant tree species. In nutrient-poor conifer forests the amount of emissions from soil is usually smaller and in this particular forest type carbon accumulation in soil continues after drainage (von Arnold et al. 2005). Whereas in fertile deciduous forests the amount of emissions is larger and emissions from soil significantly exceed removals (Minkkinen, Laine 1995; von Arnold et al. 2005). The only studies conducted in Latvia (Lupiķis, Lazdiņš 2015a, 2015b) address forests on nutrient-rich and moderate fertility drained mineral and organic soils.

Materials and methods

Emission factors of managed organic soils describe the balance of emissions and removals of a particular GHG per one hectare. An emission factor or a balance equals to the difference between emissions and removals. GHG balance consists of various components depending on the source or the sink of the gas. Emissions are divided into two groups – autotrophic and heterotrophic respiration (Figure 2). Autotrophic emissions result from the living above-ground and below-ground plant biomass, caused by metabolic processes in plants. Heterotrophic emissions are emissions caused by organisms other than plants in the ecosystem. Heterotrophic emissions result from decomposition of soil organic matter by bacteria or fungi. Besides emissions the ecosystem CO_2 balance also includes photosynthetic CO_2 uptake. CO_2 captured through photosynthesis is released in soil after plants die, thus contributing to carbon input to the soil. Throughout the process of methane (CH_4) and dinitrogen monoxide (N_2O) gas exchange removals can also occur, as a result of bacterial activity in soil.

Within the LIFE REstore project the CO_2 balance of the ecosystem was measured directly, using transparent chambers and measuring changes in CO_2 concentrations, including both photosynthetic CO_2 uptake and CO_2 emissions. Measurements can be taken only at temperatures above 0 °C. Therefore, in parallel with the measurements using the transparent chambers, CO_2 emissions of the ecosystem are measured with opaque chambers throughout the year. Since photosynthesis stops at temperatures below 0 °C, during this period the ecosystem balance equals to the ecosystem emissions. Ecosystem CH_4 and N_2O balance is independent from photosynthesis, therefore, to measure these gases, transparent chambers are not required and only opaque chambers can be used.

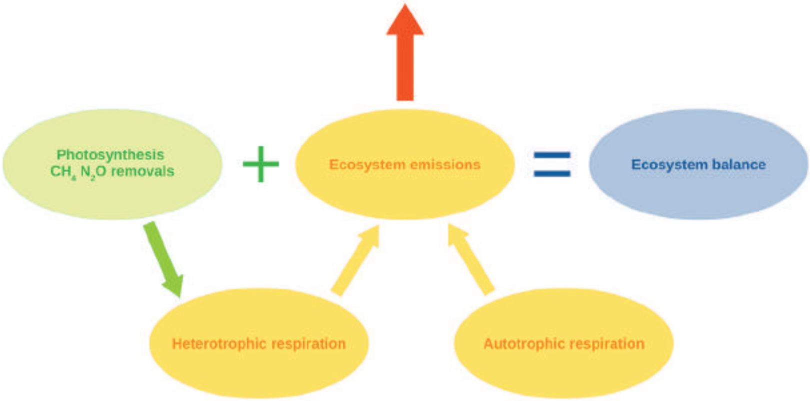

Figure 2. The components of GHG (CO_2, CH_4 and N_2O) balance.

GHG measurement site selection and description

In order to characterize GHG emissions, measurement sites were selected that represent the following land use and vegetation types:

1. Peat extraction field, where peat is extracted with milling method with an effective drainage system in the area;
2. Abandoned peat extraction field – raised bog (*Sphagnum*) peat has been extracted, and the dominant peat type on the top is fen or transitional mire peat; area is not covered with vegetation; groundwater table is not controlled and is close to the peat surface throughout the year;
3. Abandoned peat extraction field – raised bog peat has been extracted and the dominant peat type in the upper layer is fen or transitional mire peat; the area is covered with herbs and dwarf shrubs, groundwater table is not regulated and is close to the peat surface the whole year;
4. Perennial grassland on former peat extraction site, where the grass is mown, groundwater table is lowered, fen or transitional mire peat is highly decomposed;
5. Cropland on former peat extraction site, where cultivated grassland or crops are established, groundwater table is lowered, fen or transitional mire peat is highly decomposed;
6. Cropland that has replaced an abandoned peat extraction site, where legumes are grown;

groundwater table is lowered; fen or transitional mire peat is highly decomposed;

7. Highbush blueberry plantations on former peat extraction fields, groundwater table is lowered or close to the surface, raised bog or mixed peat;
8. Large cranberry plantations on former peat extraction fields on raised bog peat; groundwater table is slightly lowered or close to the surface;
9. At least 20 years old pine stands corresponding to the *Myrtillosa mel.* forest type; groundwater table is lowered; raised bog or transitional mire peat;
10. At least 20 years old birch stands, that correspond to the *Myrtillosa mel.* forest type; groundwater table is lowered; raised or transitional mire peat;
11. Relatively intact raised bog; groundwater table is not regulated; the area does not correspond to the definition of a forest according to the Forest Law (trees do not exceed the height of 5 m, the projective cover in mature stands does not exceed 20%, the area continuously covered with trees does not exceed 0.1 ha);
12. Relatively intact transitional mire; groundwater table is not regulated; the area does not correspond to the definition of a forest in the Forest Law.

Measurement sites of GHG emissions and CO_2 removals were chosen in a multistage selection procedure. First of all, using the database of areas affected by peat extraction (see Chapter 4.5), identified within the scope of the LIFE REstore research, objects representing various land use types were selected. Forest land areas were selected using data from the State Forest Register and agricultural areas – using data from the Land Parcel Information System. Highbush blueberry and large cranberry fields were selected by contacting growers of these crops. Areas of raised bogs and transitional mires were selected from spatial data of the Register of Deposits of Mineral Resources (Latvian Environment, Geology and Meteorology Centre). Afterwards such objects were selected, where there were at least three other potential GHG measurement objects located not further than within a radius of 5 kilometres. From these groups, objects representing all land use and vegetation types of the project were chosen using the random number selection method[20]. Fen peat soils (with mixed, well decomposed peat layer, where peat type cannot be identified) are represented in croplands and perennial grasslands. Other land use types have transitional mire and raised bog peat soils.

All the objects were surveyed by determining groundwater table, thickness of the peat layer, carbon-to-nitrogen ratio in the top layer of the peat and conformity of vegetation. Such objects were assessed as suitable for GHG measurements, where homogeneous cover or lack of it in at least three trial objects exceeded 4 ha, and that could be accessed by car the whole year through permanent roads and the walking distance from the roadside to the centre of the object was no longer than 300 metres. In the final selection stage discussions with owners and managers of the objects, who agreed on the collaboration within the scope of the project, took place, choosing measurement objects that are evenly distributed across the whole territory of Latvia. Taking into account that agricultural areas, which correspond to the criteria of organic soils, were found only in certain locations, adjustments in the initial method were made and all the areas of the respective objects were included in the study regardless of areas located nearby representing other land use and vegetation types.

The specified measurement objects according to their land use types and their coordinates in the LKS-92 system are shown in Table 2. The location of sampling objects is shown in Figure 3. In total, measurements were taken in 41 objects, including five LIFE REstore demo sites.

20 Random selection within subsets, QGIS, https://docs.qgis.org/2.8/en/docs/user_manual/processing_algs/qgis/vector_selection_tools/randomselectionwithinsubsets.html.

Table 2. Measurement objects, geographic coordinates, land use types and vegetation types.

Vegetation types	No.	Land use type	Object	Coordinates in LKS-92	
				X	Y
1	1	Peat extraction site	Cena Mire	499684	298592
	2		Kaigu Mire	473990	286134
	3		Silgulda Mire	704240	359743
2	4	Area is not covered with vegetation	Silgulda Mire	704510	358291
	5		Ezera Mire	581334	383752
	6		Lauga Mire	541899	347554
3	7	Are is covered with herbs and dwarf shrubs	Silgulda Mire	704228	357282
	8		Ezera Mire	581393	383881
	9		Cepļa Mire	649492	344598
4	10	Perennial grassland on former peat extraction site	Kašķu Mire	474539	307542
	11		Stabulnieku I Mire	672977	254237
	12		Krista Mire	667644	275163
5	13	Cropland on an abandoned peat extraction field – cereal	SIA “Mārupe”	496872	301104
	14		Diervanīne Mire	684572	290033
	15		Gaveņpurs Mire	414206	332834
6	16	Cropland in former peat extraction site – vegetables	Diervanīnes bog	667644	275163
	17		Lielsala Mire	399127	358300
	18		Cena Mire	498832	297918
7	19	≥20 years old spruce or pine stands	Cepļa Mire	649724	344213
	20		Kaigu Mire	475572	289107
	21		Lambārte Mire	519248	262263
8	22	≥20 years old birch stands	Lielsala Mire	399202	358138
	23		Silgulda Mire	705132	357013
	24		Plece Mire	348265	289795
9	25	A relatively intact part of raised bog	Lielsala Mire	398834	356924
	26		Lauga Mire	540783	348378
	27		Ķemeri Mire	471655	304132
10	28	A relatively intact part of transition mire	Igerīšu Mire	537206	329581
	29		Kazu Mire	549444	348588
	30		Kalnezers Mire (Līņu Lake)	545025	282281
11	31	Highbush blueberry plantations in former peat extraction sites	SIA “Arosa-R”	475702	285359
	32		ZS “Dālders”	696273	332971
	33		SIA “Very Berry”	647451	370776
12	34	Large cranberry plantations in former peat extraction sites	ZS “Dālders”	696367	332947
	35		SIA “Very Berry”	647346	370823
	36		SIA “Shpats & Sons”	541375	347656

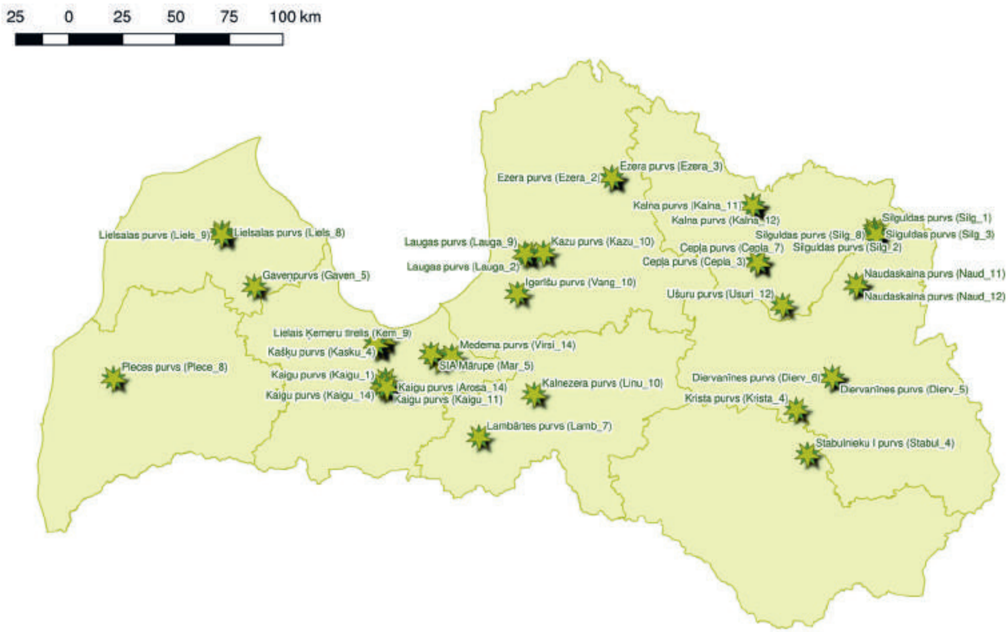

Figure 3. Location of sampling sites.

The characteristic landscapes of measurement sites are shown in Figure 4–12.

Figure 4. Peat extraction field in Silgulda Mire. Photo: G. Spalva.

Figure 5. Extracted peat deposit with poorly developed vegetation in Cena Mire. Photo: G. Spalva.

Figure 6. Highbush blueberry plantation in Kaigu Mire. Photo: G. Spalva.

Figure 7. Large cranberry plantation in Naudaskalns Mire (ZS "Dālders"). Photo: G. Spalva.

Figure 8. Perennial grassland in Kašķu Mire. Photo: G. Spalva.

Figure 9. A relatively intact transition mire, Kazu Mire. Photo: G. Spalva.

Figure 10. A relatively intact part of a raised bog, Lielsala Mire. Photo: G. Spalva.

Figure 11. A silver birch stand in the extracted part of Lielsala Mire. Photo: G. Spalva.

Figure 12. A Scots pine stand in the extracted part of Kaigu Mire. Photo: G. Spalva.

A schedule of gas sampling was made, whose purpose was to ensure that the sampling in each object is carried out regularly, once a month with less than one week displacement over a period of 24 months. In the schedule, the measurement sites were divided in nine routes depending on the location of measurement objects and the estimated time consumption for the measurements. The measurement plan was prepared in collaboration with an Estonian company "Severitas", which provided outsourcing services of gas sample collection and analyses within the scope of the project.

Soil analyses

During the initial stage soil samples were collected in all objects, where the peat layer was thicker than 20 centimetres. The thickness of the peat layer was measured with a probe at least in five potential gas sampling sites. If the peat layer was less than 1 m thick, soil samples were collected up to the depth of 0.8 m, including from the mineral soil layer, whereas, if the peat layer run deeper – up to the bottom edge of the peat layer or down to the depth of 150 cm. Peat samples were collected with a probe for unmixed samples (Figure 13), dividing the borehole in 10 cm thick soil layers. In the mineral soil layer samples were collected vertically after each 10 cm and sample volume was 100 cm3. A peat core collected with a 50 cm long probe was divided into 10 cm long segments.

Figure 13. Soil probing. Photo: I. Bebre.

Soil sample preparation and analyses were done according to the ICP Forests guidelines (Cools, de Vos 2010), in compliance with the quality criteria laid down in the chapter 16 (König et al. 2010). Soil analyses were carried out in the Latvian State Forest Research Institute “Silava” (LSFRI Silava), Forest Environment Laboratory. Moisture content was determined according to the ISO 11465 standard, texture of the mineral soil – according to ISO 11277, soil density and proportion of coarse fraction in mineral soil – according to ISO 11272, pH_{CaCl2} – according to ISO 10390, carbonate content was determined with a calcimeter – according to ISO 10693, the total carbon content with elemental analyser – according to ISO 10694, ash content in peat was determined by incinerating peat at 600 °C, the total nitrogen content – with a modified Kjeldahl method, according to the ISO 11261, phosphorus, potassium, calcium and magnesium content in peat – according to ISO 11466.

Water sample collection and analyses

Water samples were collected from two groundwater wells in each object once every two months – four times during the vegetation period. Water sample collection, storage, processing and analyses were carried out according to the methods of ICP Forests[21]. Water samples were collected, processed and stored according to the ISO 5667-3:2018 standard, water pH was measured according to ISO 10523, electrical conductivity – according to LVS EN 27888:1993, ammonium ions – according to LVS ISO 7150/1:1984, nitrate ions were determined with Skalar TOC analyser, phosphate ions – according to LVS EN ISO 6878 (2005), potassium, calcium and magnesium content – according to LVS EN ISO 7980 (2000) and LVS ISO 9964-3:2000 (2000), but the total nitrogen content – according to LVS ISO 11261 (2002).

Methods for measuring GHG emissions

From December 1, 2016 till November 2018, ecosystem gas – CO_2, CH_4 and N_2O – exchange measurements were taken, using the opaque chamber method (Hutchinson, Livingston 1993) and the transparent chamber method, which enables to determine the CO_2 removals caused by photosynthetic activity of ground vegetation (Salm et al. 2012).

21 ICP Forests, http://icp-forests.net/.

Measurements with opaque chambers

The closed chamber consists of two parts – the chamber which is made from PVC and is 40 cm in height, with a diameter of 50 cm and volume of 65 L (Figure 15) and a collar (Figure 14), which is placed in soil permanently – during the whole observation period. Chambers are set up in five repetitions in each study object. The chamber is painted white in order to prevent the temperature from rising too high when taking measurements. On the upper edge of the collar a groove is made, which corresponds to the diameter of the chamber. This groove is water-filled in order to ensure a closed environment and prevent the access of air, when attaching the chamber.

Gas samples were collected, taking the following actions. At least 24 hours before gas sampling a collar is placed in soil (Figure 14) in order to set up sampling chambers (Figure 15). The area chosen for placing the collar should be as even as possible. In those areas without movement of machines, collars remained in soil during the whole study period[22]. Collars are placed evenly – in a 10–15 m distance from the groundwater table measuring well. In wet soils around the sampling sites foot-bridges should be placed, so that movement does not affect the content of gases. On the outer edge of the collar there is a channel that can be filled with water to ensure a seal between the chamber and the collar to prevent the access of air, which could impact the quality of samples. When collecting samples in winter, when water is freezing, the edge of the chamber is covered with snow. In order to ensure the quality of the first sample (collected immediately after installing the chamber), the chamber should be ventilated before sampling by swinging into the air 4–5 times in order to dispose stale air. Then the chamber is placed on the collar, making sure that the edges of the collar are enclosed by water and there are no berry bushes, branches or other things stuck in it that would allow the access of air in the chamber. On the chamber headspace there is an opening to insert the tube of the gas sample collection syringe. When the tube is inserted in the opening, the sample bottle and the syringe are attached. When attaching the bottle, it should be checked if it is fitting tightly. When connecting the bottle to the pipe system, it is recommended to hold the bottle by squeezing the bottle plug, not the glass part of it.

Gas samples were collected, inserting a tube in a chamber with an attached syringe by which the air from the chamber was collected in evacuated (0.3 mbar) 100 ml bottles. From each chamber four samples were collected at intervals of 20 minutes within one hour: immediately after installing the chamber on the collar, as well as after 20, 40 and 60 minutes (Augustin et al. 1998). Samples were placed in a specially prepared and labelled sample boxes so that each sample had its cell address, depending on the chamber and the minute, when samples are collected. Gas sampling within the scope of the LIFE REstore project was provided by experts from the Estonian company "Severitas". In parallel with the measurements of GHG emissions under field conditions measurements of the factors affecting GHG emissions were taken, including air temperature, oxygen dissolved in water, electrical conductivity, water turbidity, pH and oxidation-reduction potential; as well as samples were collected to determine the nitrate (NO_3^-) and ammonium (NH_4^+) content in groundwater. At the same time, soil temperature was measured at four depths – 5; 10; 20; 30 cm, and the electrical conductivity and moisture content in soil was determined.

The collected gas samples were transported to the Climate Change laboratory of the Department of Geography of University of Tartu in order to determine ecosystem emissions – concentrations of GHG (CO_2, CH_4 and N_2O). Analyses were done with the *Shimadzu GC-2014* gas chromatograph, equipped with an electron capture detector, flame ionisation detector and Loftfield autosampler (Loftfield et al. 1997). The level of each gas emissions is calculated, assuming that the level of gas concentration in environment changes linearly. In order to ensure linear changes, chambers should meet the requirements of certain minimum area and volume. When using small chambers, gas saturation may occur, therefore an exponential or a degree equation should be used in calculations. When collecting samples, storage and handling protocols should be filled. Information sheets should be attached to each box, containing

22 Except for areas, where it is not possible to leave collars in soil during the whole vegetation period. In these areas collars are inserted in soil a day before collecting gas samples and are removed immediately after sampling. Collars are sealed from the outside with wet sand or soil.

information about the origin of samples. A repeated identification of samples helps to prevent the risk of disarranging them.

In order to ensure sampling accuracy, it is important to follow the time, when the measurements are taken, therefore a timer should be used. Sample collection from the first chamber is started at the zero minute, from the second – at the second minute, from the third – at the third minute etc., accordingly samples at the 20th minute are taken from the first chamber, at the 22th – from the second, at the 24th – from the third, etc. Chambers are left on the rings for the whole measurement time – 1 hour. When removing them, it is reassured that the chambers were fully sealed.

In order to ensure the quality of the final results, it is important to visit each sample plot at the same time. In this way processes and existing linkages can be observed more successfully, when monitoring changes in soil emissions over a time period.

Figure 14. A collar placed in soil. Photo: I. Bebre.

Figure 15. Opaque flux measurement chambers. Photo: I. Bebre.

There is a chance that sample bottles are prepared poorly and the air has not been sucked out. There are two solutions to this problem – extra bottles should always be carried along, or the air can be sucked out with a syringe by opening the sampling bottle's stopper and pumping air with a syringe as long as it jumps to the base.

Measurements with transparent chambers

Similarly as in the case with opaque chambers, the closed chambers consist of two parts – the chamber, that is made from a transparent organic glass and is 40 cm high, 50 cm in diameter and 65 L in volume, and a collar, which remains in soil over the whole observation period. Collars are installed in five repetitions at each site. When collecting samples, the chamber is placed on the collar, which is painted white, in order to avoid heating up during application. On the upper edge of the collar there is a water-filled groove which corresponds to the diameter of the chamber in order to ensure a closed environment and prevent access of the air, when attaching the chamber.

Changes in CO_2 concentration were measured with the *EGM-5* portable CO_2 gas analyser. A significant drawback of transparent chambers is the greenhouse effect that occurs inside of them. Affected by sunlight, the temperature inside the chamber rises rapidly, therefore a closed chamber is equipped with a cooling system that slows down the temperature rise inside the chamber. The chamber is also equipped with temperature sensors that are connected to the *EGM-5* measuring device, in order to follow the changes in temperature.

A measurement consists of the following steps. After switching on the device, it is stabilised (approx. 5 min.). In order to ensure an accurate and optimal performance of the device, it should be allowed to heat up. A sound signal and a screen message indicate that the device is ready. The water is poured in the ring groove. When the device is ready, the previously ventilated, transparent chamber is placed on the collar. Then the *EGM-5* measurement unit is attached. Measurements are started with a fully transparent chamber. The measurement duration is approximately 150 seconds. When the measurement is completed, the chamber is covered with a shroud that decreases the incoming light by 25% and the measurements are repeated for 150 seconds. The same is repeated with a shroud that blocks 50% of light and with an opaque shroud. When changing the shrouds, the chamber should be repeatedly ventilated. The previously mentioned operations are repeated on all the collars of the respective object. In parallel, photosynthetically active radiation is measured with the *LI-190R* sensor.

Data quality control

The analysed gas samples were subjected to quality control, by verifying if the changes in gas concentrations are linear. In Figure 16 an example is shown, in which the trend of CO_2 concentration change is linear and meets the quality requirements.

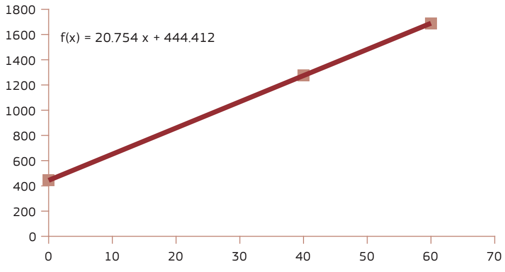

Figure 16. Changes in CO2 concentration over time.

One of the quality criteria is the R^2 value. Data quality is sufficient if the R^2 value exceeds 0.95. Sometimes it can be observed, that some samples are faulty or an error has occurred during the analyses. Low quality data are deleted, and the rest of the measurement data are saved.

Another example is shown in Figure 17, where one of the values does not follow the linear trend of changes of the gas concentration. In this case the second value is faulty. This value is further excluded from calculations.

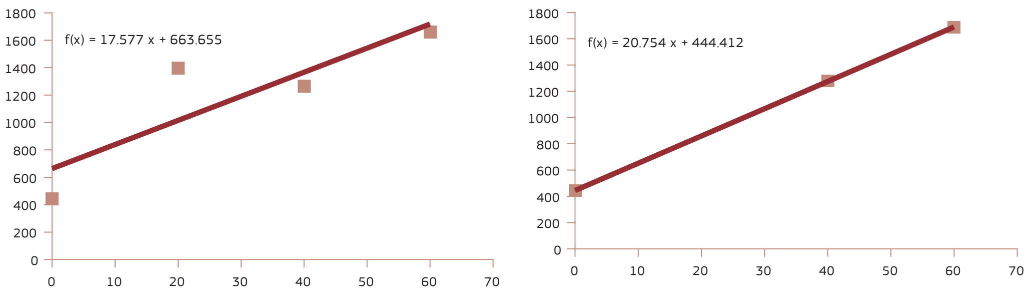

Figure 17. Exclusion of the faulty measurements from the analysis.

Forest litter collection and tree increment measurements

In sample plots, which were established in forests and highbush blueberry plantations, aboveground litter was also collected, which characterizes the carbon content. Five litter traps were set up in forests (Figure 18), and in blueberry plantations – 10 litter traps. Litter was collected once a month. After collecting litter samples from the whole year, samples were mixed together, their biomass, as well as carbon and nitrogen content was determined. Analyses were carried out according to the ICP Forests manual (Pitman et al. 2010).

Figure 18. Litter traps in a Scots pine stand. Photo: K. Polmanis.

Another significant source of carbon input in forest ecosystem is fine roots. In order to calculate the amount of carbon, which enters the soil after fine roots die, equations from carbon exchange models, which describe the carbon input in soil, are used (de Wit et al. 2006). In order to characterize carbon input, which is caused by tree volume increment, increment cores are collected from forest stands, from which the increment rings of the past two years are measured and carbon sequestration in biomass is calculated. Biomass is calculated according to the method developed by J. Liepiņš (Liepiņš et al. 2017) and the method developed by I. Liepa (Liepa 1996) for calculations of changes in tree height.

Results and discussion

The summary of the results of soil analyses of each land use type in LIFE REstore research objects is given in Tables 3–5. In topsoil (0–20 cm deep) pH ranged from 2.5 (raised bog or transitional mire peat, not covered with vegetation) to 6.7 (cropland, well decomposed transitional mire or fen peat). In pine stands on transition mire peat pH in the topsoil was 2.6. In almost all of the land use types pH values in deeper layers did not differ from the topsoil except for cropland and perennial grassland, where pH values of the topsoil were higher. Regardless of land use type, soil density of the topsoil was significantly higher. The lowest density was in peat extraction sites and in abandoned peat extraction sites, as well as intact bogs. Perennial grasslands and croplands have the densest soil.

Table 3. pH and density of different soil layers.

Land use and vegetation type	pH $CaCL_2$					Soil density, kg m^{-3}				
	0–10 cm	10–20 cm	20–30 cm	30–40 cm	40–50 cm	0–10 cm	10–20 cm	20–30 cm	30–40 cm	40–50 cm
≥20 years old silver birch stands	3.2	3.1	3.3	3.4	3.5	180	143	152	152	196
≥20 years old Norway spruce or Scots pine stands	2.6	2.5	2.5	2.5	2.5	199	163	160	129	103
Cropland on former peat extraction site – cereals	5.2	5.1	5.0	4.8	4.8	358	357	318	321	322
Cropland on former peat extraction site – legumes	6.7	6.6	6.4	6.0	5.8	320	305	231	231	254
Cranberry plantations on former peat extraction sites	2.7	2.6	2.6	2.6	2.7	149	88	99	92	87
Perennial grassland on former peat extraction site	5.5	5.5	5.4	5.2	5.0	470	480	421	306	349
Peat extraction site	2.9	3.0	3.1	3.2	3.3	124	106	100	94	105
Area covered with herbs and dwarf shrubs	3.0	2.8	2.7	2.7	2.8	116	106	93	89	86
Area not covered with vegetation	2.5	2.5	2.5	2.6	2.7	105	88	87	93	88
An intact part of a raised bog	2.8	2.8	2.8	2.8	2.8	151	129	98	101	75
An intact part of a transition mire	2.9	3.0	3.0	3.0	3.0	136	112	102	128	98
Blueberry plantations on former peat extraction sites	3.1	3.1	3.2	3.3	3.3	153	121	106	183	110

Carbon (C) content in the topsoil (0–20 cm) was 325–556 g kg^{-1}. The highest C content was detected in abandoned peat extraction fields covered with herbs and dwarf shrubs. In deeper soil layers C content did not differ significantly. Nitrogen (N) content in topsoil (0–20 cm) was 7–34 g kg^{-1}. The highest N content was detected in cropland, perennial grassland and forest stands. The N concentration was relatively high also in raised bog soil, which could be the reason for the high CO_2 and CH_4 emissions. In deeper soil layers the N content was decreasing in forest land, but in cropland it did not differ from the average values in the topsoil. Usually, phosphorus (P) deficiency has been observed in afforested areas on organic soils. Decrease in tree growth rate and withering are characteristic features of phosphorus and potassium deficiency, when the available nutrient reserves are depleted. P content in topsoil (0–

20 cm) in study objects was 0.1–2.3 g kg^{-1}. The highest P content was detected in cropland, perennial grassland and forest stands. In cropland, P content was about two times higher than in forest land, but in peat extraction fields – 2–3 times lower than in forest. It means that phosphorus containing fertilizers, e.g. wood ash, are required, when afforesting this land use type. In deeper soil layers P content was lower in forest land, cropland and perennial grassland.

Table 4. Carbon, nitrogen and phosphorus content in soil.

Land use and vegetation type	Carbon content, g kg^{-1}					Nitrogen content, g kg^{-1}					Phosphorus content, g kg^{-1}				
	0–10 cm	10–20 cm	20–30 cm	30–40 cm	40–50 cm	0–10 cm	10–20 cm	20–30 cm	30–40 cm	40–50 cm	0–10 cm	10–20 cm	20–30 cm	30–40 cm	40–50 cm
≥20 years old silver birch stands	518	529	538	548	494	19	18	17	17	14	0.5	0.3	0.5	0.3	0.3
≥20 years old Norway spruce or Scots pine stands	538	536	536	540	534	14	13	10	7	8	0.6	0.2	0.2	0.1	0.1
Cropland on former peat extraction site – cereals	469	489	517	557	551	32	34	31	28	29	2.3	1.5	1.2	0.8	0.6
Cropland on former peat extraction site – legumes	427	380	521	529	471	30	27	30	29	24	0.9	0.8	0.6	0.4	0.5
Cranberry plantations on former peat extraction sites	498	538	546	542	542	9	7	8	7	8	0.3	0.2	0.2	0.1	0.2
Perennial grassland on former peat extraction site	326	326	375	398	441	18	16	17	16	15	1.0	0.8	0.6	0.5	0.3
Peat extraction site	546	547	557	563	571	11	7	9	9	12	0.2	0.3	0.3	0.1	0.1
Area covered with herbs and dwarf shrubs	512	523	530	541	539	11	8	8	9	9	0.3	0.2	0.2	0.2	0.2
Area not covered with vegetation	555	556	573	579	580	9	9	10	8	9	0.1	0.2	0.2	0.1	0.1
An intact part of a raised bog	518	514	526	523	515	15	11	13	11	12	0.3	0.2	0.2	0.2	0.2
An intact part of a transition mire	531	535	543	545	552	7	7	7	8	9	0.2	0.2	0.2	0.2	0.2
Blueberry plantations on former peat extraction sites	543	555	549	557	556	11	10	9	9	10	0.3	0.3	0.3	0.1	0.1

Potassium (K) is the second element, whose deficiency is related to growth deterioration in forest stands on organic soils. K content in the topsoil (0–20 cm) was 0.2–4.3 g kg^{-1}. In cropland, K content was up to 10 times higher than in forest land and up to 20 times higher than in peat extraction sites and abandoned peat extraction areas. In deeper soil layers K content was lower. Analyses show that in order to successfully afforest peat extraction fields, K-containing fertilizers should be used.

Calcium (Ca) content in topsoil (0–20 cm) was 1.2–19.6 g kg^{-1}. The highest Ca content was detected in cropland and perennial grassland. The lowest Ca content was detected in intact areas and in Scots pine stand. In deeper soil layers Ca content did not differ significantly from the average values in topsoil.

Magnesium (Mg) is another element often related to tree growth disturbances in afforested areas on organic soils. However, in Latvia it has not been proved that Mg is the primary factor limiting tree growth in afforested peatlands. Mg content in topsoil (0–20 cm) was 0.5–8.8 g kg^{-1}. In cropland Mg content was 4–8 times higher than in forest stands. In contrary to the Ca content, Mg concentration in deciduous and coniferous stands did not differ significantly. In deeper soil layers Mg content was lower in most of the study objects.

Table 5. Potassium, magnesium and calcium content in soil.

Land use type	Potassium, g kg^{-1}					Calcium, g kg^{-1}					Magnesium, g kg^{-1}				
	0–10 cm	10–20 cm	20–30 cm	30–40 cm	40–50 cm	0–10 cm	10–20 cm	20–30 cm	30–40 cm	40–50 cm	0–10 cm	10–20 cm	20–30 cm	30–40 cm	40–50 cm
≥20 years old silver birch stands	0.5	0.3	0.3	0.2	0.3	8.9	10.0	10.8	10.9	11.3	0.7	0.6	0.6	0.6	0.7
≥20 years old Norway spruce or Scots pine stands	0.6	0.4	0.2	0.1	0.0	2.6	1.6	1.9	2.1	2.2	0.7	0.5	0.5	0.6	0.6
Cropland on former peat extraction site – cereals	1.3	1.1	0.9	0.7	0.4	17.3	19.6	21.9	23.0	25.6	3.6	3.2	3.3	2.8	2.4
Cropland on former peat extraction site – legumes	4.3	2.7	0.7	0.6	1.8	12.8	16.5	27.1	28.5	15.1	8.1	8.8	8.2	5.0	4.0
Cranberry plantations on former peat extraction sites	0.4	0.3	0.3	0.3	1.3	2.1	1.8	1.5	1.4	1.5	0.8	0.9	0.7	0.6	0.6
Perennial grassland on former peat extraction site	2.1	2.0	0.9	0.9	0.6	14.7	16.9	20.1	19.1	18.8	2.6	2.5	2.9	2.5	2.2
Peat extraction site	0.3	0.3	0.2	0.1	0.4	3.6	4.1	6.2	5.8	7.4	1.0	1.0	1.7	1.0	1.0
Area covered with herbs and dwarf shrubs	0.6	0.5	0.2	0.1	0.1	5.9	5.2	3.9	3.6	3.5	0.9	0.8	0.7	0.5	0.5
Area not covered with vegetation	0.2	0.2	0.1	0.1	1.0	2.0	1.4	1.5	1.7	1.9	0.7	0.5	0.4	0.4	0.4
An intact part of a raised bog	0.5	0.4	0.5	0.3	0.1	1.5	1.2	1.2	1.7	1.6	0.6	0.5	0.5	0.5	0.5
An intact part of a transition mire	0.6	0.5	0.4	0.4	0.3	3.0	2.7	2.2	2.2	2.1	1.0	0.7	0.6	0.6	0.5
Blueberry plantations on former peat extraction sites	0.8	0.4	0.4	0.2	0.2	8.4	8.9	9.4	10.7	12.0	1.0	0.9	0.8	0.8	1.1

Considering the differences in soil density, a more objective indicator to characterize nutrient content is their availability recalculated to one square unit. Figures 19–22 show the stock of carbon and other major biogenic elements per 1 ha 0–50 cm deep. The largest carbon stock was found in cropland (on average 802 t C ha^{-1}), the lowest – in intact areas, peat extraction fields and abandoned peat extraction areas. In forest, in depth of 0–50 cm the carbon stock was about two times larger than in intact areas. It means that changes in surface height after drainage are mostly caused by mechanical surface deflation, for example, in forest land a decrease in surface height by 50 cm would not have an impact on soil carbon stock, comparing with a field, where peat has been extracted recently.

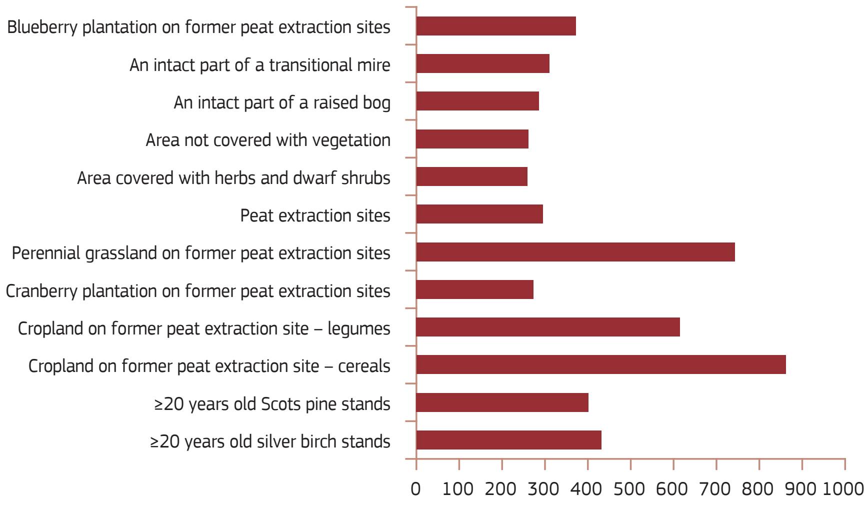

Figure 19. Soil carbon stock.

N stock in peat in depth of 0–50 cm was 4–52 t ha^{-1}. In cropland and perennial grassland N stock was up to five times larger than in forest land and up to 10 times larger than in other land use types. It means that also N input can significantly improve the results of afforestation or growing other type of vegetation.

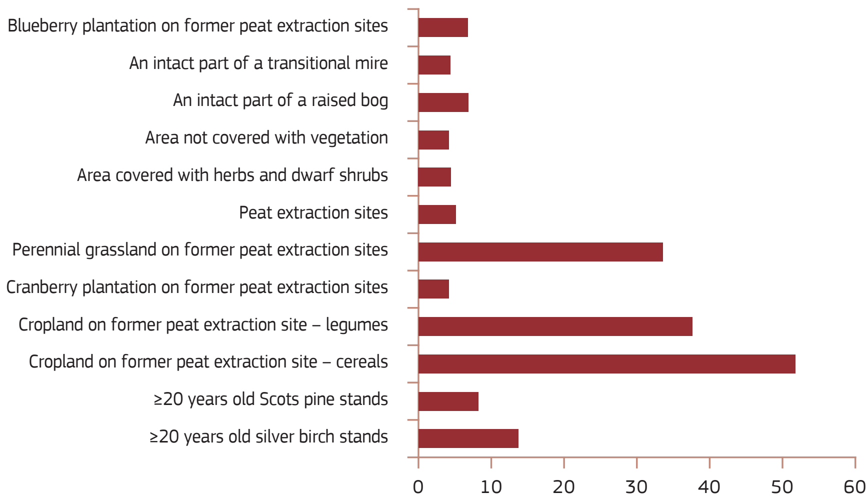

Figure 20. Nitrogen stock in soil.

P stock in peat in depth of 0–50 cm was 0.1–2.2 t ha^{-1}. In cropland and perennial grassland P stock was up to 10 times larger than in forest land and up to 20 times larger than in other land use types. A comparison of P stock in different land use types and different vegetation types confirms the assumption that application of phosphorus-containing fertilizers can significantly increase tree growth in afforested peatlands or facilitate growth of vegetation typical to mire ecosystem in the process of rewetting.

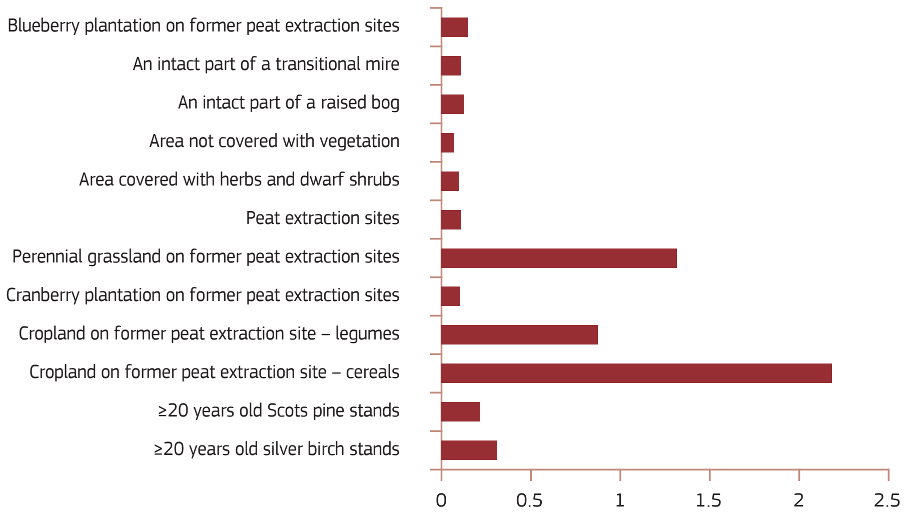

Figure 21. Phosphorus stock in peat.

K stock in peat in depth of 0–50 cm was 0.1–3.0 t ha^{-1}. In cropland and perennial grassland the average K stock was at least 10 times higher than in other land use types, including forest land. K stock in forest land did not significantly differ from K stock in intact peatlands, but it should be taken into account that in drained forests a deeper aerated soil layer is available to plants, therefore availability of both K and P, as well as other nutrients in drained areas is significantly higher.

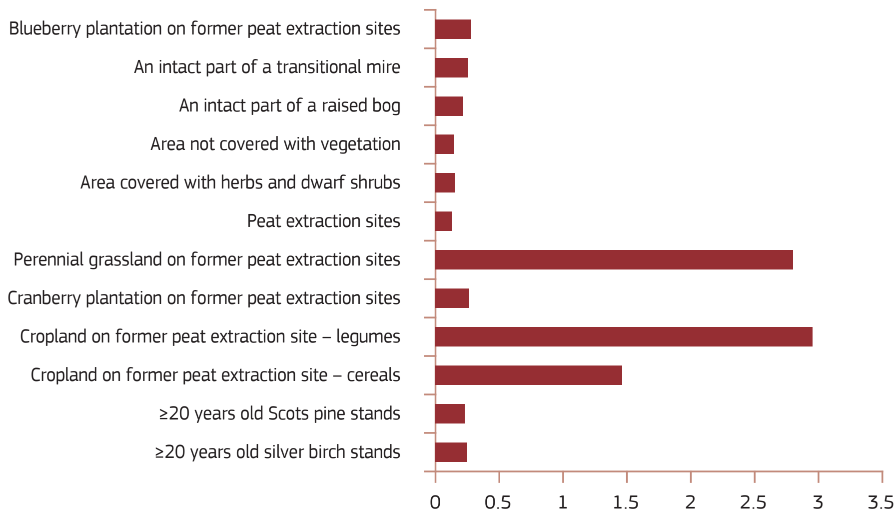

Figure 22. Potassium stock in soil.

Study results confirm the scientific knowledge gained so far on the effect of drainage on CO_2 exchange between the mire ecosystem and the atmosphere. There is a presumption that a human intact bog is a net CO_2 sink. After drainage, peat decomposition and mineralization are increasing rapidly and CO_2 emissions occur, but CO_2 uptake in photosynthesis of growing plants does not compensate for CO_2 losses from the ecosystem, and as a result soil carbon stock is decreasing. It is also confirmed by the LIFE

REstore results, where positive net ecosystem emissions (GHG emissions exceed CO_2 removals) were found in all land use types examined in this study (Figure 23).

Smaller net emissions (the difference between emissions and CO_2 removals) were recorded in cranberry plantations, where the net emissions were 0.75 t CO_2-C ha^{-1} annually (Figure 24). Although the annual amount of emissions in cranberry plantations (2.6 t CO_2-C ha^{-1} annually) is larger than in peat extraction fields (1.09 t CO_2-C ha^{-1} annually) and in abandoned peat extraction fields (0.95 t CO_2-C ha^{-1} annually), CO_2 capture by vegetation through photosynthesis can partially compensate for CO_2 emissions. Overall, it can be assumed that establishment of cranberry plantations on former peat extraction fields contributes to decrease of net CO_2 emissions. A similar situation arises, when an abandoned peat extraction site is afforested with conifers, where the average net CO_2 emissions equal to 0.96 t CO_2-C ha^{-1} annually. For a comparison – if peat extraction still continues, net emissions equal to 1.09 t CO_2-C ha^{-1} annually, in abandoned peat extraction fields that are not covered with vegetation – 0.95 t CO_2-C ha^{-1} annually, but in abandoned fields covered with vegetation that is not a tree stand – 1.85 t CO_2-C ha^{-1} annually. A decrease in CO_2 emissions, compared to herb and dwarf shrub vegetation development in a partially extracted peat field, is possible also if the abandoned peat extraction site if afforested with silver birch (net emissions – 1.15 t CO_2-C ha^{-1} annually) or a blueberry plantation is established on it (net emissions– 1.13 t CO_2-C ha^{-1} annually). The greatest positive effect of tree and shrub planting is caused by CO_2 sequestration in the living biomass. Transforming peat extraction fields into croplands, where cereals or other crops are cultivated, or into grassland, used for grazing or forage production, shows negative results. In this case CO_2 emissions significantly increase, and the net emissions reach 5.0 t CO_2-C ha^{-1} annually, 3.7 t CO_2-C ha^{-1} annually and 3.2 t CO_2-C ha^{-1} annually, accordingly, in croplands where cereals or legumes are cultivated and in grassland.

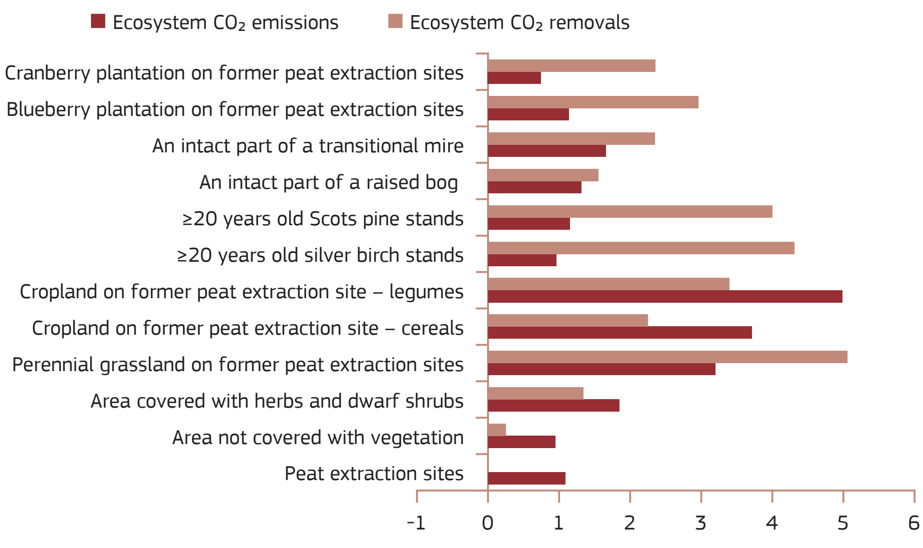

Figure 23. Ecosystem CO_2 removals and emissions, depending on land use type.

Comparing these results, calculated within the scope of the LIFE REstore Project, with the IPCC default CO_2 emission factors (Figure 24) given in the 2013 IPCC guidelines, in all land use types lower emissions have been found. For afforested areas, blueberry and cranberry plantations, perennial grassland and peat extraction fields the difference in these values exceeds twice.

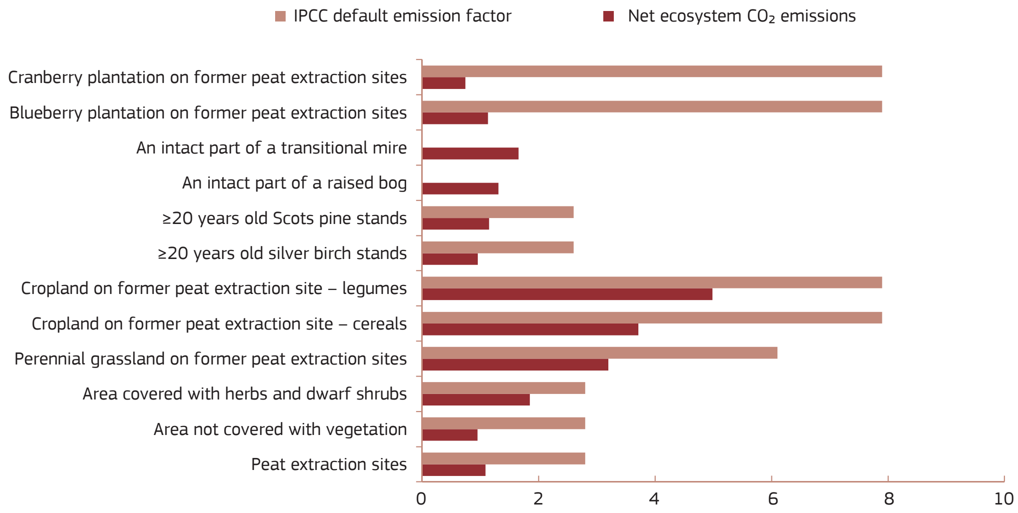

Figure 24. LIFE REstore CO_2 emission factors and the IPCC default CO_2 emission factors.

These differences are caused by a number of factors. Firstly, the 2013 IPCC emission factors that correspond to climate in Latvia, were calculated on the basis of results obtained in the central and northern parts of Europe. Taking into account that climatic factors have a significant impact on CO_2 emissions and that in warmer climatic conditions higher emissions occur, the current 2013 IPCC emission factors are not applicable to conditions in Latvia. However, it should be considered that the measurement period included year 2017 that was high in rainfall and year 2018, when summer and autumn were dry. This could have significantly influenced also the results of this study, significantly decreasing CO_2 emissions in the first year and increasing in the second. In order to make far-reaching conclusions and apply LIFE REstore results in practice, further observations are required to characterize the impact of meteorological conditions on CO_2 emissions over a longer period of time. Observations in study areas should be continued for at least 10 years in order to find out if tendencies of changes in GHG emissions correspond to the hypothesis put forward. Long-term observations are also required to determine how long after land use change GHG emissions can reach balance.

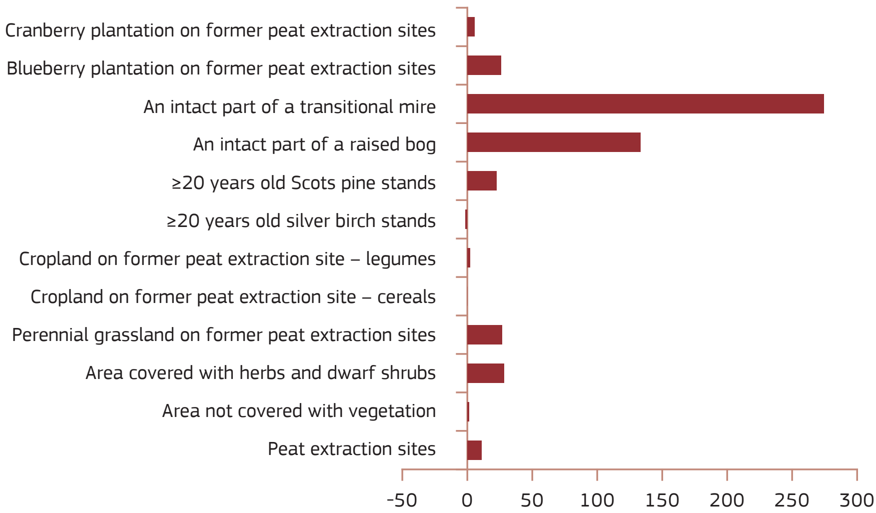

Figure 25. CH_4 emissions depending on land use type.

In contrary to CO_2 emissions, CH_4 emissions usually decrease after drainage. This was confirmed also after summarizing LIFE REstore results on CH_4 emissions (Figure 25). Higher CH_4 emissions were found in intact transition mires and raised bogs, which were used in calculations to characterize GHG emissions at a steady stage conditions after rewetting. In transition mires and raised bogs CH_4 emissions reach 274 kg CH_4-C ha^{-1} annually and 133 kg CH_4-C ha^{-1} annually accordingly. The lowest CH_4 emissions were found in afforested cropland, where methane emissions do not exceed 1.0 kg CH_4-C ha^{-1} annually. In areas afforested with Scots pine, a small removal was found, i.e. emission values were negative (-1.4 kg CH_4-C ha^{-1} annually). It means that soil microorganisms are consuming methane. Methane CO_2 equivalent in calculations of GHG emissions is 25, i.e. 1 t CH_4 correspond to 25 t CO_2.

In this study it was concluded that reclamation of an abandoned peat extraction field will not lead to decrease in CH_4 emissions. Transformation of peat extraction fields into croplands and afforestation with conifers is an exception. After-use types that result in rise of groundwater table, contributes to increase in CH_4 emissions.

The highest N_2O emissions, as expected, were found in cropland (Figure 26). Accordingly, in croplands, where cereals and legumes are cultivated, N_2O emissions are 7.8 kg N_2O-N ha^{-1} annually and 4.5 kg N_2O-N ha^{-1} annually. The relatively high N_2O emissions in cropland are related to the high amount of nitrogen (N) available to plants and microorganisms, provided by regular application of fertilizers. Considerable N_2O emissions were also found in transition mire and blueberry plantation, accordingly 1.4 kg N_2O-N ha^{-1} annually and 0.9 kg N_2O-N ha^{-1} annually. Also in blueberry plantations nitrogen fertilizer was applied, which is reflected in the results, however, fertilizer dosages are smaller than in intensively cultivated croplands. It is relatively harder to explain N_2O emissions from transition mires. Even more so because the total nitrogen content in transition mire soil is not higher than in raised bogs, cranberry plantations or peat fields, where N_2O emissions are insignificant. The most of N_2O emissions (> 80%) in transition mires are produced in March and April, when snow and frozen soil surface have melted. It is related to bacterial activity in soil and their interactions. Production of N_2O emissions is a complicated process, which is still not entirely clear. A significant rise in N_2O emissions in study objects in the spring months has increased the total annual N_2O emissions. In order to obtain more precise N_2O emission data, the frequency of data collection should be increased, particularly in the spring and summer months, when the impact of snow melting and fertilizer application can be observed. The CO_2 equivalent of nitruous oxide (dinitrogen monoxide) in the calculations of GHG emissions is 298, i.e. 1 t N_2O correspond to 298 t CO_2.

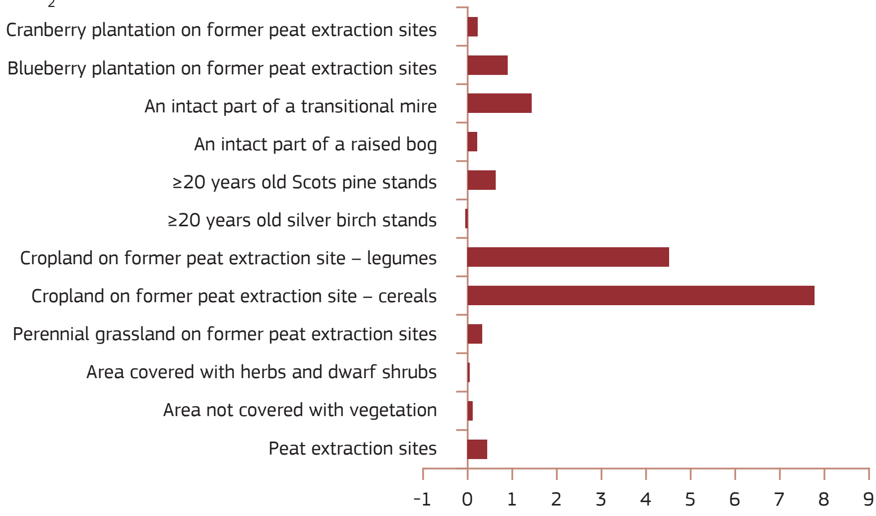

Figure 26. N_2O emissions for different land use types.

The cumulative GHG emissions from soil that reflect CO_2-C, CH_4-C and N_2O-N emissions in CO_2 equivalents are shown in Figure 27. The figure shows that from all the after-use scenarios viewed in this study the lowest GHG emissions from soil are ensured by afforestation with coniferous species and establishment of large cranberry plantation. The net emissions from soil in case of these scenarios accordingly are 4.3 t CO_2 eq. ha^{-1} annually and 5.2 t CO_2 eq. ha^{-1} annually. A similar amount of emissions is produced in silver birch stands (5.5 t CO_2 eq. ha^{-1} annually). It should be noted that CO_2 sequestration in tree biomass, deadwood and ground litter, which provide significant additional removals, are not included here. Whereas, if reclamation in an area is not carried out and it naturally overgrows with non-forest vegetation, the total GHG emissions are 7.9 t CO_2 eq. ha^{-1} annually. There are relatively good results from the blueberry plantation establishment scenario, where emissions are slightly lower (net emissions equal to 6.4 t CO_2 eq ha^{-1} annually), compared to an abandoned peat field covered with vegetation. However, in all the after-use scenarios the emissions are slightly higher, comparing with an active peat extraction site (net emissions equal to 4.2 t CO_2 eq ha^{-1} annually) or an abandoned peat field that is not covered with vegetation (3.3 t CO_2 eq. ha^{-1} annually). Increase in emissions is related to the increase in vegetation cover, which provides a favourable environment for microorganisms, and thus contributing to CH_4 and CO_2 emissions.

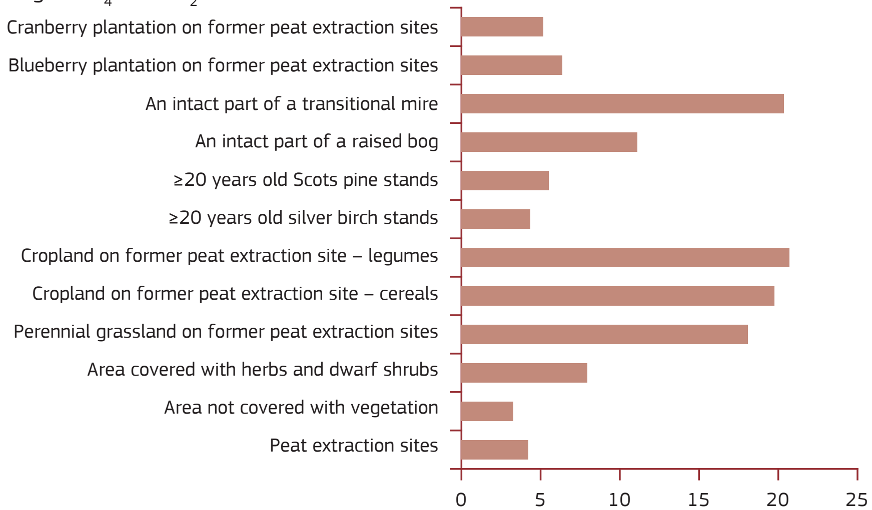

Figure 27. Net GHG (CO_2, CH_4, N_2O) emissions, recalculated to CO_2 equivalents.

Several times larger increase in soil emissions is caused by abandoned peat extraction fields that are transformed into agricultural land by growing crops or establishing pasture. These after-use scenarios contribute to the increase of the total amount of GHG emissions the most. When growing cereals, GHG emissions from soil exceed 20 t CO_2 eq ha^{-1} annually.

A decrease or an increase in GHG emissions from soil, comparing with a peat field, depending on the land use type, is shown in Figure 28. CO_2 removals of the living tree, shrub and herb biomass are not included in the comparison. The total ecosystem gas exchange that characterizes the impact of different land use types is shown in figure 29. Rewetting is not included in this graph, assuming that rewetting returns the ecosystem in its natural state and emissions, that are not caused by anthropogenic factors, should not be accounted.

Comparison of different scenarios should not be done mechanically, but it should be assessed reasonably, which conditions are more suitable for different scenarios. For example, a forest can grow in areas, where without additional activities, e.g. fertilization, not even ground vegetation would grow, whereas transformation to cropland is possible only in those areas, where the residual peat layer consists of fertile fen peat, causing significantly higher GHG emissions than transition mire and raised bog peat. Adjusting emission factors of fen peat soils is the next step to improve the national GHG inventory system and to obtain objective data on the impact of different climate change mitigation measures on GHG emissions.

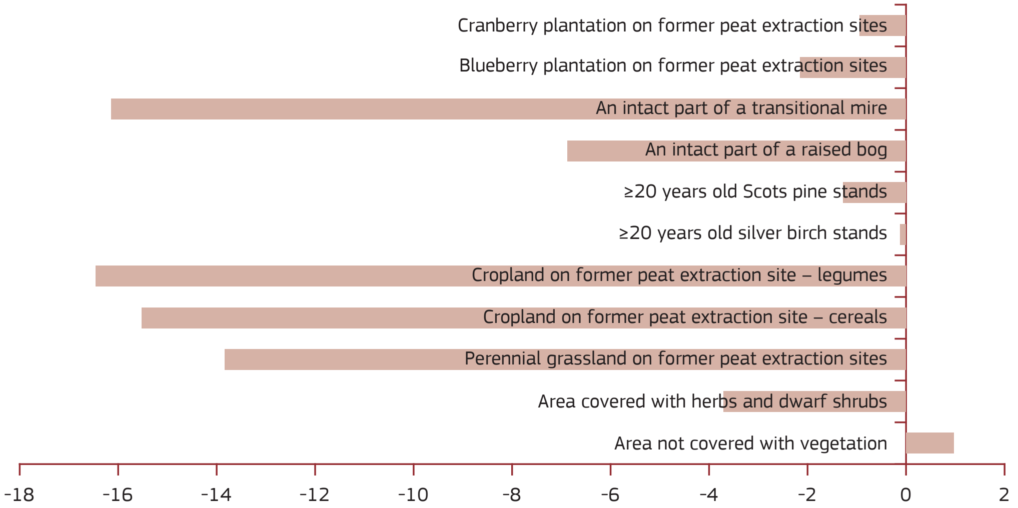

Figure 28. Decrease in net GHG emissions from soil in case of various land use and vegetation types, comparing with GHG emissions from peat extraction sites.

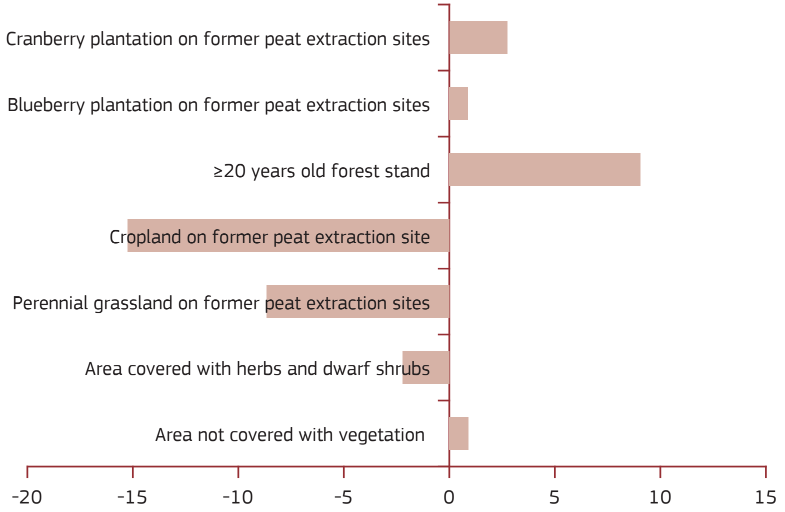

Figure 29. A decrease in net GHG emissions in case of various land use and vegetation types, comparing with GHG emissions from peat extraction fields over a period of 30 years.

Conclusions

According to the LIFE REstore results, the best after-use scenarios for climate change mitigation from those assessed within the study, are establishment of large cranberry plantations, which can be done in areas, where the layer of raised bog peat is thick enough, and afforestation with Scots pine, which can be done on both raised bog and transition mire peat soil. Abandoned peat extraction fields that are transformed into agricultural land cause a significant increase in emissions from soil, therefore this scenario should be avoided. Comparing the results of the study with the 2013 IPCC default emission factors, it was found that the 2013 IPCC default emission factors significantly exceed the results of LIFE REstore.

3.2. Climate change mitigation measures in managed wetlands

Measures that reduce GHG emissions and enhance CO_2 removals in the LULUCF sector are described in the reports that Latvia have to submit within the scope of Conferences of the Parties to the United Nations Framework Convention on Climate Change and relevant EU regulations.

Climate change mitigation policy of the LULUCF sector in Latvia is based on the measures listed in the Rural Development Plan (Figure 30). The largest reduction in emissions is ensured by measures to be implemented in forest land. Measures related to wetland management are not planned, including those directly aimed at reduction of GHG emissions from organic soils. One of the main reasons why wetlands and organic soils are not included in the GHG reduction policy is insufficient knowledge about GHG emissions from soil and the impact of different management approaches. Therefore, the results of the LIFE REstore project have an essential role not only in the improvement of GHG inventory in the LULUCF sector, but also in planning of climate change policy measures and development of projections.

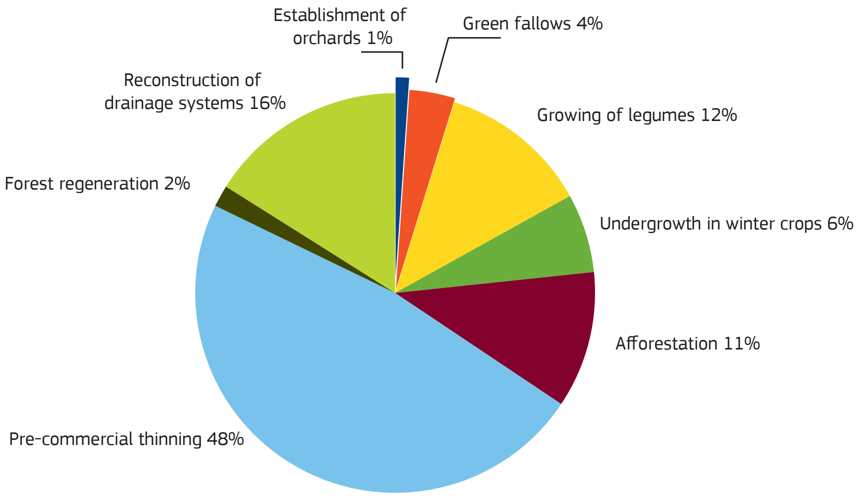

Figure 30. Summary of the impact of proposed climate change mitigation measures (2017 report on policies, measures and GHG projections submitted to the European Commission[23]).

Soil GHG emission factors elaborated within the LIFE Restore project that are integrated with the default GHG factors from the Intergovernmental Panel on Climate Change (IPCC) guidelines (Eggleston et al. 2006; Hiraishi et al. 2013), in order to characterize GHG emissions depending on nutrient availability, land use type and vegetation type, are summarised in Table 6, and indicators of changes in carbon stock in other carbon pools are summarized in Table 7. Whereas the probability of changes in land use and vegetation type is shown in Figure 31, where also such land use change categories are shown, for whose impact assessment the data of the LIFE REstore project have been used.

23 Reporting on policies and measures under Article 13 and on projection under Article 14 of Regulation (EU) No. 525/2014 of the European Parliament and of the Council, https://cdr.eionet.europa.eu/lv/eu/mmr/art04-13-14_lcds_pams_projections/pams/envwqhspw/.

Table 6. Assumptions on GHG emissions from soil used in the study to characterize the impact on climate change, tonnes CO_2 eq. ha^{-1} annually.

GHG	Nutrient supply[24]	Forest on drained organic soil	Forest on wet organic soil	Cropland on drained organic soil	Grassland on drained organic soil	Cranberry plantation	Blueberry plantation	Bare peat extraction field	Peat extraction field covered with herbaceous vegetation	Rewetted area (former peat extraction field)	Peat extraction field
CO_2	Poor	0.83	-0.84	13.27	12.11	3.79	4.52	7.08	-0.84	-0.84	4.45
CO_2	Rich	0.83	1.83	13.27	12.11	3.79	4.52	7.08	1.83	1.83	4.45
DOC	Poor	1.14	0.88	1.14	1.14	0.88	1.14	1.14	0.88	0.88	1.14
DOC	Rich	1.14	0.88	1.14	1.14	0.88	1.14	1.14	0.88	0.88	1.14
CH_4	Poor	0.25	3.07	0.09	1.34	0.16	0.88	1.43	3.07	3.07	0.37
CH_4	Rich	0.25	7.2	0.09	1.34	0.16	0.88	1.43	7.2	7.2	0.37
CH_4 from ditches	Poor	0.14	-	1.46	1.46	0.68	1.46	0.27	-	-	0.68
CH_4 from ditches	Rich	0.14	-	1.46	1.46	0.68	1.46	0.27	-	-	0.68
N_2O	Poor	1.31	-	6.09	2.01	2.01	2.01	1.31	-	-	0.14
N_2O	Rich	1.31	-	6.09	3.84	3.84	3.84	1.31	-	-	0.14
Total	Poor	3.67	3.1	22.05	18.06	7.51	10.01	11.23	3.1	3.1	6.77
Total	Rich	3.67	9.91	22.05	19.89	9.34	11.84	11.23	9.91	9.91	6.77

Table 7. Assumptions used in the study about changes in carbon stock in different carbon pools in organic soils after reaching a steady state, tonnes CO_2 ha^{-1} annually.

Land use type	Carbon pool and its formation period	Unit	Value
Forest on drained organic soil	Living trees	tonnes C ha^{-1}	93.15
		transition period	40
	Deadwood	tonnes C ha^{-1}	4.5
		transition period	40
	Ground vegetation	tonnes C ha^{-1}	2
		transition period	5
Forest on wet organic soil	Living trees	tonnes C ha^{-1}	58.62
		transition period	40
	Deadwood	tonnes C ha^{-1}	3.35
		transition period	40
	Ground vegetation	tonnes C ha^{-1}	2
		transition period	5

24 Good nutrient supply corresponds to fen and transitional mire soil, poor – to raised bog soil.

Table 7 continued

Land use type	Carbon pool and its formation period	Unit	Value
Cropland on drained organic soil	Living trees	tonnes C ha^{-1}	-
		transition period	-
	Deadwood	tonnes C ha^{-1}	-
		transition period	-
	Ground vegetation	tonnes C ha^{-1}	5
		transition period	1
Grassland on drained organic soil	Living trees	tonnes C ha^{-1}	-
		transition period	-
	Deadwood	tonnes C ha^{-1}	-
		transition period	-
	Ground vegetation	tonnes C ha^{-1}	6.8
		transition period	3
Large cranberry plantation	Living trees	tonnes C ha^{-1}	-
		transition period	-
	Deadwood	tonnes C ha^{-1}	-
		transition period	-
	Ground vegetation	tonnes C ha^{-1}	13.6
		transition period	5
Highbush blueberry plantation	Living trees	tonnes C ha^{-1}	-
		transition period	-
	Deadwood	tonnes C ha^{-1}	-
		transition period	-
	Ground vegetation	tonnes C ha^{-1}	25
		transition period	5
Bare peat extraction field	Living trees	tonnes C ha^{-1}	-
		transition period	-
	Deadwood	tonnes C ha^{-1}	-
		transition period	-
	Ground vegetation	tonnes C ha^{-1}	-
		transition period	-
Peat extraction field, covered with herbaceous vegetation	Living trees	tonnes C ha^{-1}	-
		transition period	-
	Deadwood	tonnes C ha^{-1}	-
		transition period	-
	Ground vegetation	tonnes C ha^{-1}	6.8
		transition period	3
Rewetted areas (former peat extraction fields)	Living trees	tonnes C ha^{-1}	-
		transition period	-
	Deadwood	tonnes C ha^{-1}	-
		transition period	-
	Ground vegetation	tonnes C ha^{-1}	6.8
		transition period	3
Peat extraction fields	Living trees	tonnes C ha^{-1}	-
		transition period	-
	Deadwood	tonnes C ha^{-1}	-
		transition period	-
	Ground vegetation	tonnes C ha^{-1}	-
		transition period	-

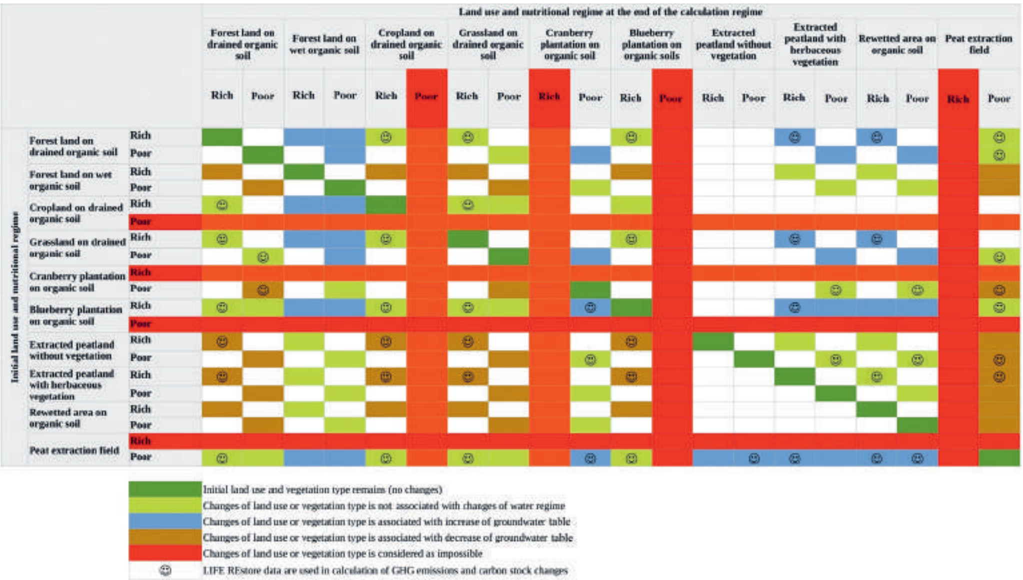

Figure 31. Probability assessment of different land use and vegetation type changes on organic soils (unpublished data from the LIFE REstore project and expert assumptions).

Using the indicators given in Table 6, Table 7 and Figure 31, a logical analysis of assumptions should be carried out, evaluating each situation separately – whether the planned scenario is possible in the current situation and, if not – whether any actions could be taken that would change the situation so that implementation of the scenario becomes possible. For example, it cannot be assumed that transformation of cropland on organic soil to a cranberry plantation will decrease GHG emissions to the level corresponding to the emission difference in these land use types, because most likely this kind of transformation is not possible in practice and regardless of the formal land use change, GHG emissions, except for N_2O, will not decrease significantly. At the same time, after finishing peat extraction, depending on characteristics of the residual peat layer, the peat field can correspond to the criteria that characterize areas with both nutrient-rich and poor soil material. By increasing or decreasing the thickness of the residual peat layer, the nutrient supply in topsoil becomes sufficient or insufficient, accordingly. Growing conditions can change after interruption of fertilization, for example, when transforming a blueberry plantation into a forest or a rewetted area, nitrogen added to the soil will leach out soon and nutrient supply will significantly deteriorate, resulting in decrease of GHG emissions. The opposite process occurs, when lowering groundwater table or ensuring water flow in soil, thus improving soil aeration, which results in increased nutrient supply to plants. Therefore, in an area with poorly developed herbaceous vegetation, forest stands that correspond to the higher site indexes can grow. Development of forests on wet organic soils can be assessed as a potential scenario in case of afforestation, if drainage systems are not maintained or are not efficient, and the purposely grown forest stand is gradually replaced with tree species typical to forests on wet organic soils, reaching tree dimensions that correspond to the respective forest types. It should be taken into account that growing conditions in peat soils can change, for example, by removing the nutrient-poor or nutrient-rich soil layer or draining of soils to the depth at which tree roots can reach the mineral soil or peat layers with better nutrient supply.

Within the LIFE REstore project, such areas affected by peat extraction are classified as degraded, where forest land vegetation has not yet developed, that are not transformed into cropland, perennial grassland, or areas of buildings, where peat extraction is abandoned, where rewetting to restore peat-forming vegetation has not been carried out or that have not been flooded. In Table 6 and Table 7 land use types "Bare peat extraction field" and "Peat extraction field covered with herbaceous vegetation" correspond to this category. In these areas various restoration types are possible and, considering the differences in hydrological regime between different parts of restored areas, in most cases different restoration types should be combined. Figure 32 shows after-use scenarios that can be implemented without significantly changing growing conditions. GHG emissions are calculated for a period of 30 years (the time period left until the end of commitments made under the Paris Agreement).

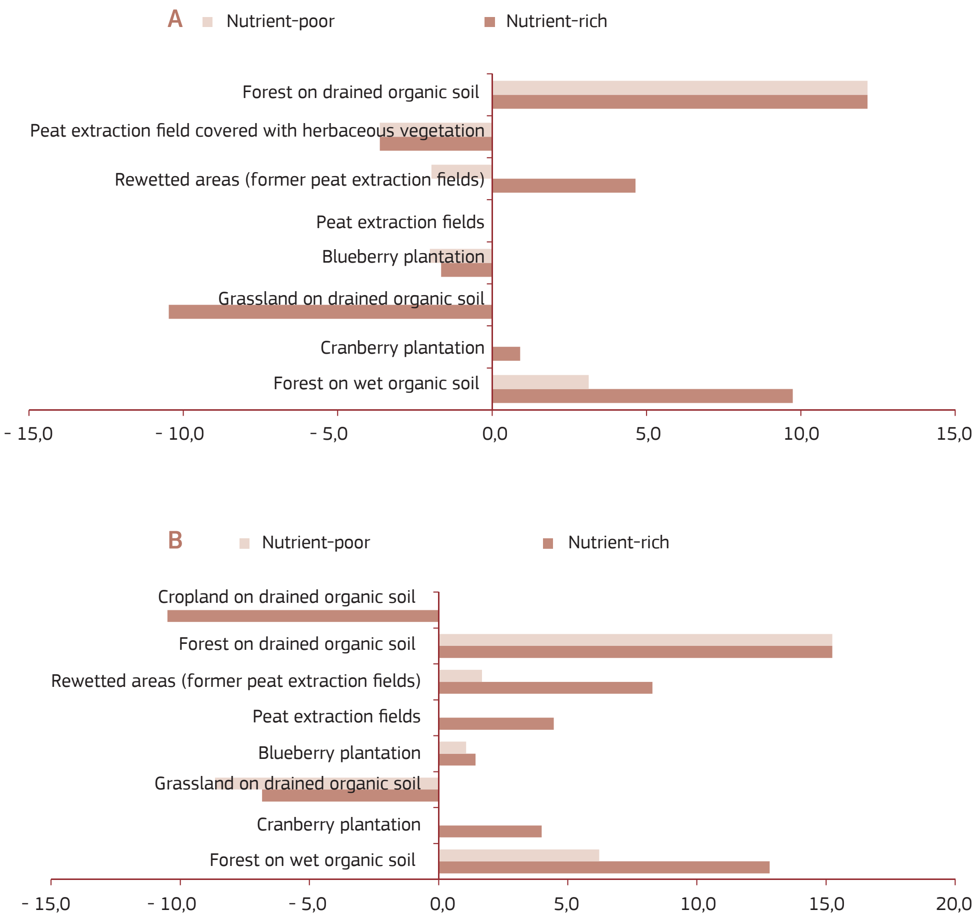

Figure 32. A comparison of different scenarios in areas affected by peat extraction: A – bare peat extraction field; B – peat extraction field, covered with herbaceous vegetation.

The largest reduction of GHG emissions is instigated by afforestation, including forest stands on wet organic soils. The longer the calculation period, the larger amount of CO_2 removals is provided by the afforestation scenario. In areas with higher groundwater table, where nutrient supply is insufficient also for plant communities typical to forests on wet organic soils, the largest reduction of GHG emissions is caused by rewetting, except in cases, when plant biomass cannot compensate for GHG emissions from the soil. The reduction of GHG emissions, according to the LIFE REstore results, can be reached also by growing berries in peat extraction fields.

The LIFE REstore project has made a significant contribution to raising awareness of the impact of wetland management on GHG emissions by identifying measures with the largest potential for reduction of GHG emissions, as well as avoiding exaggerated assumptions about the possibilities to reduce emissions from cropland and perennial grassland on organic soils. However, the insufficient knowledge about the factors that affect GHG emissions limits the planning of peat field management, when introducing climate change mitigation measures. Lack of knowledge is most evident, when assessing the impact of organic soil management on GHG emissions and short-term changes, for example, the impact of final felling or periodical rise in groundwater table on GHG emissions from soil in managed wetlands, cropland, grassland and forests on organic soils.

3.3. The calculation system of GHG emissions from managed wetlands

Within the scope of the National GHG inventory, calculations of GHG emissions and removals for the LULUCF sector are made by LSFRI Silava with support from the Ministry of Agriculture according to the 2006 IPCC guidelines (Eggleston et al. (eds.) 2006) and 2013 IPCC guidelines (Hiraishi et al. 2013). So far calculations in Latvia have been made, using the default emission factors from the guidelines. A summary of levels of calculation methods and emission factors used in the GHG inventory is given in Table 8.

The aim of LIFE REstore was to replace the default emission factors and activity data with scientifically verified national emission factors and activity data. GHG emission factors, which can be used to characterize emissions, depending on land use type, are summarized in Table 8.

Table 8. A summary of emission factors (EF) used in calculations of GHG emissions and removals.

Emission source	CO_2		CH_4		N_2O	
	Method	EF	Method	EF	Method	EF
Changes in carbon stock in wetlands, where land use type has not been changed						
living biomass	Tier 2	CS	-	-	-	-
dead organic matter	Tier 2	CS	-	-	-	-
organic soil	Tier 1	D	-	-	-	-
Emissions and removals, resulting from drainage or other activities in organic and mineral soils						
organic soil	Tier 2	CS	Tier 1	D	Tier 1	D

Tier 1 – Tier 1 methods (default activity data from guidelines), Tier 2 – Tier 2 methods (national activity data), CS – country-specific emission factors (EF), D – default EF.

Activity data

Information about the areas of managed wetlands since 2009 is provided by the National Forest Inventory (NFI), but in 2018 data from two NFI cycles (2004–2008 and 2009–2013) were used, extrapolating land use change in further years according to the changes that occurred in the second cycle of the NFI. After finishing the third cycle of the NFI, in 2019 LSFRI Silava will make a recalculation of land use change data. Information about wetland areas, that is offered by the State Land Service, State Forest Service and Central Statistical Bureau, is used to compare data and to assess the potential mistakes in the NFI data.

Already in 2018 LSFRI Silava introduced LIFE REstore activity data in the LULUCF sector of the GHG inventory, in order to characterize changes in areas of abandoned and active peat extraction sites (Butlers, Ivanovs 2018).

Changes in carbon stock

Assumptions that are used in calculations of carbon stock in living and dead wood in wetlands are summarized in Table 9. According to the 2006 IPCC guidelines, decomposition time of deadwood was assumed to be 20 years.

Table 9. Assumptions for calculations of changes in carbon stock in living and dead wood in wetlands.

Year	Wetlands with tree vegetation, 1000 ha	Increase in living biomass stock		Tree density, kg m^{-3}	Natural dying, m^3 ha^{-1}	Biomass recalculation factors		Carbon content, kg $tonnas^{-1}$
		million m^3	m^3 ha^{-1}			From stem to crown	From stem to roots	
1990	189.25	0.06	0.33	0.41	0.06	0.31	0.31	523
1991	191.55	0.07	0.37	0.41	0.07	0.31	0.31	523
1992	193.42	0.08	0.41	0.41	0.08	0.31	0.31	523
1993	194.24	0.08	0.42	0.41	0.08	0.31	0.31	523
1994	195.72	0.09	0.44	0.41	0.09	0.31	0.32	523
1995	196.29	0.09	0.45	0.41	0.09	0.31	0.32	523
1996	197.92	0.09	0.46	0.41	0.09	0.31	0.32	523
1997	199.26	0.09	0.46	0.41	0.09	0.31	0.32	523
1998	201.05	0.09	0.47	0.41	0.09	0.31	0.32	523
1999	201.20	0.09	0.47	0.41	0.09	0.32	0.32	523
2000	202.54	0.1	0.47	0.41	0.09	0.32	0.32	523
2001	203.12	0.1	0.47	0.41	0.09	0.32	0.32	523
2002	204.27	0.1	0.47	0.41	0.09	0.32	0.32	523
2003	205.96	0.1	0.47	0.41	0.09	0.32	0.32	523
2004	206.59	0.1	0.46	0.41	0.1	0.33	0.32	524
2005	206.71	0.1	0.46	0.41	0.1	0,33	0.32	524
2006	210.16	0.1	0.46	0.41	0.1	0.33	0.32	524
2007	97.62	0.18	1.85	0.41	0.4	0.33	0.32	524
2008	97.62	0.18	1.85	0.41	0.4	0.33	0.32	524
2009	97.62	0.18	1.85	0.41	0.43	0.33	0.32	524
2010	97.62	0.18	1.85	0.41	0.43	0.33	0.32	524
2011	97.62	0.18	1.85	0.41	0.43	0.33	0.32	524
2012	97.62	0.17	1.73	0.41	0.40	0.33	0.32	524
2013	97.62	0.17	1.79	0.41	0.53	0.33	0.32	524
2014	97.62	0.18	1.84	0.41	0.54	0.34	0.30	524
2015	97.62	0.18	1.84	0.41	0.53	0.33	0.30	524
2016	97.62	0.18	1.84	0.41	0.54	0.33	0.30	524

Source: MEPRD (2018).

The emission factor for calculation of changes in soil carbon stock as a result of drainage according to the 2013 IPCC guidelines (Hiraishi et al. 2013) for the Table 2.1 is 2.8 t C ha^{-1} annually. After the end of the LIFE REstore project, an emission factor for peat extraction sites and croplands obtained within the study will be used in GHG inventory, additionally distinguishing objects, where peat extraction has been ceased for a longer period of time. For the former wetlands, where peat extraction is ceased and that are afforested, CO_2 emission factors usually applied for forest stands are used, but if afforestation has not occurred yet – CO_2 emission factors for perennial grassland or cropland on fertile soils, accordingly, 2.6 t CO_2-C ha^{-1}, 6.1 t CO_2-C ha^{-1} and 7.9 t CO_2-C ha^{-1} annually, thus preventing under- or overestimation of potential emissions. After the end of the project, emission factors elaborated within LIFE REstore will be used also for these land use types.

Data about peat extraction for horticulture (Figure 33) were obtained from statistical reports. An extrapolation method was used in GHG inventory, in order to obtain data on certain periods where official data were not available. Carbon content in air-dry peat, according to the 2006 IPCC guidelines (Table 7.5), was assumed as 0.45 t C per tonne of peat, the relative moisture content in peat – 40%.

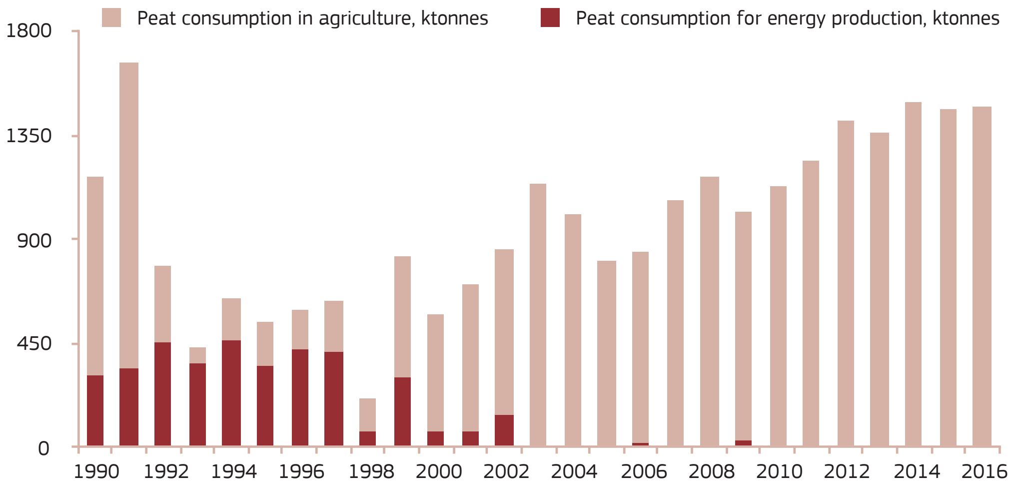

Figure 33. Peat extraction for horticulture and power industry. Source: Central Statistics Bureau.

CH_4 emissions from drained organic soils

Drainage of wetlands in Latvia is carried out in abandoned or active peat extraction fields. CH_4 emissions were calculated according to the equation 2.6. from the 2013 IPCC guidelines:

$$CH_{4\_organic} = A * \left(\left(1 - Frac_{ditch}\right) * EF_{CH\_4\_land} + Frac_{ditch} * EF_{CH\_4\_ditch} \right) \text{ where}$$

$CH_{4\_organic}$ = CH_4 emissions from drained organic soils, kg CH_4 yr^{-1};
A= Area of drained organic soils, ha;
$EF_{CH\_4\_land}$ = Direct CH_4 emission factor for drained organic soils, kg CH_4 ha^{-1} yr^{-1};
$EF_{CH\_4\_ditch}$ = CH_4 emission factor for ditches in drained organic soils, kg CH_4 ha^{-1} yr^{-1};
$Frac_{ditch}$ = Area of ditches in drained organic soils.

The CH_4 emission factor for drained organic soils is 6.1 kg CH_4 ha^{-1} annually (Table 2.3 of the 2013. IPCC guidelines), emission factor for ditches in drained areas is 542 kg CH_4 ha^{-1} annually (Table 2.4 of the 2013 IPCC guidelines). According to the results of spatial data analysis of peat extraction sites, it is assumed that the density of ditches in peat extraction fields is 0.07 ha per 1 ha of peat fields (7%). The default value of ditches according to the 2013 IPCC guidelines in peat fields is 5%, i.e. the same as in croplands and perennial grasslands on organic soils. If a peat extraction field is reported as a forest stand, perennial grassland or cropland, default CH_4 emission factor of the respective land use type for fertile soils was used (Table 10).

Table 10. Default CH_4 emission factors*.

GHG	Unit	Forest	Cropland	Perennial grassland	Peat extraction fields
CH_4	kg CH_4 ha^{-1}	2.5	-	16	6.1
CH_4 from ditches	kg CH_4 ha^{-1}	217	1165	1165	542
Share of the ditch area	-	3%	5%	5%	5%

** Source: Hirashi et al. (2013).*

After finishing the LIFE REstore research, the elaborated GHG emission factors for managed organic soils will be used. For ditches that are not included in the LIFE REstore research, the default emission factors will be continuously used.

Direct N_2O emissions from drained organic soils

Direct N_2O emissions from drained organic soils were calculated according to the equation 2.7 of the 2013 IPCC guidelines:

$$N_2O-N_{OS} = \left[\left(F_{OS,C,G,Temp} \cdot EF_{2CG,Temp}\right) + \left(F_{OS,F,W,Temp,NR} \cdot EF_{2F,Temp,NR}\right)\right];\ \textit{where}$$

N_2O-N_{OS} = *Direct N_2O-N emissions from managed/ drained organic soils, kg N_2O-N yr.*

F_{OS} = *managed / drained organic soils, ha. Abbreviations C, G, F, W, Temp, NR means cropland, grassland, forest land, wetlands, climate region and nutritional regime.*

EF_2 = *N_2O emission factor for drained/ managed organic soils, kg N_2O–N ha^{-1} yr^{-1}.*

The activity data are area sizes of wetlands on drained organic soils, where land use type has not been changed for at least 20 years. So far in the GHG inventory the default N_2O emission factor was used (Table 11) for drained soils according to the Table 2.5 of the 2013 IPCC guidelines.

Table 11. Default N_2O emission factor for drained organic soils.

Land use type	Climatic/ vegetation zone	Emission factor (kg N_2O-N ha^{-1} annually)	95% confidence interval	
Wetlands for peat extraction	Boreal and temperate	0.3	-0.03	0.64

Source: Hiraishi et al. (2013).

For those objects, where peat extraction has been cased and that are afforested, N_2O emission factors of forest stands should be used, but if the peat extraction fields are not afforested – N_2O emission factors normally used for perennial grasslands or croplands on fertile soils. The values of these emission factors accordingly are 2.6 kg N_2O-N ha^{-1}, 13 kg N_2O-N ha^{-1} and 8.2 kg N_2O-N ha^{-1} annually.

After the end of the LIFE REstore project, GHG emission factors for organic soils, elaborated within the scope of the project, will be used in the GHG inventory for calculations of direct N_2O emissions.

Uncertainty of activity data and emission factors

A significant indicator is the uncertainty of activity data and emission factors, which is very high in the LULUCF sector. Uncertainty is calculated according to the 2006 IPCC guidelines. The uncertainty of NFI activity data is calculated with the percentage error method (Table 12). A summary of uncertainties of default GHG emission factors in peat extraction sites are given in Table 13.

Table 12. A summary of the uncertainty of wetland areas (2016).

Land use type	The number of NFI sample plots	A part of NFI sample plots in wetlands, %	Uncertainty, %
Wetlands	1123	7.0	5.7
Wetlands that have not changed the land use type	1119	6.9	5.9
Drained soils	68	0.4	24.2
Naturally wet soils	1051	6.5	6.1
Land that was transformed into wetland	4	0.03	13.4

Table 13. Summary of inaccuracies in default GHG emission factors for peat extraction fields.

Land use type	GHG	EF, unit	95% confidence interval		Uncertainty, %
Drained organic soils in wetlands	CO_2	2.8 t CO_2-C ha^{-1} annually	1.1	4.2	55
Drained organic soils in wetlands	CH_4	6.1 kg CH_4 ha^{-1} annually	1.6	11	77
Ditches in drained organic soils in wetlands	CH_4	542 kg CH_4 ha^{-1} annually	102	981	81
Drained organic soils in wetlands	N_2O	0,3 kg N_2O-N ha^{-1} annually	-0.03	0.64	112

3.4. LIFE REstore project contribution to the improvement of GHG inventory

LIFE REstore has significantly contributed to improving activity data rows and elaboration of emission factors for organic soils to ensure compatibility with 2006 IPCC guidelines, as well as 2013 IPCC guidelines (application of Tier 2 methods for several main sources of GHG emissions, including drained organic soils in forests, croplands, perennial grasslands and managed wetlands, also in rewetted areas) and development of quality control procedures to use alternative activity data for verification of the results of calculations. Introduction of the results will have an impact on activity data and emissions calculations in all land use types within the LULUCF sector.

After introducing the results of the study, the calculated amount of GHG emissions will decrease on average by 2 million t CO_2 eq. annually in the LULUCF sector (Figure 34). Changes in emission factors are attributed to the whole period (1990–2016), therefore the amount of GHG emissions accounted during the calculation period will decrease similarly.

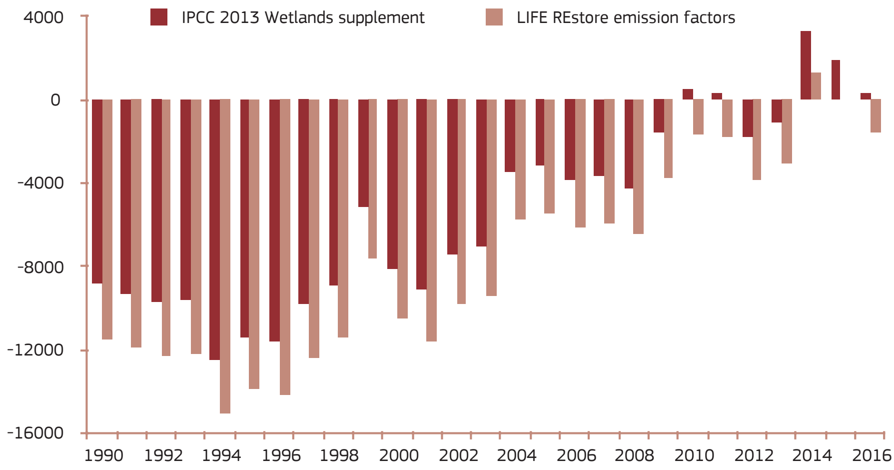

Figure 34. The impact of introduction of LIFE REstore results on GHG emission accounting in the LULUCF sector in Latvia.

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4. STUDIES BY LIFE RESTORE IN AREAS AFFECTED BY PEAT EXTRACTION

4.1. Geology and stratigraphy of peatlands

Laimdota Kalniņa

Summary

Moderate climate with higher precipitation than evaporation, as well as slightly undulated relief, clayey, poorly permeable deposits in relief depressions and hydrological regime are favourable factors that have contributed to the formation and development of peatlands in the territory of Latvia. Over the last hundred years, development of many mires has been halted by peatland drainage (for agricultural use and for peat extraction) and by their overgrowth with forest, both naturally and as a result of human activity.

Within LIFE REstore project, it was necessary to determine the properties of residual peat in cutaway peatlands, in order to select the most suitable after-use scenario, including a complex of reclamation measures, and to minimize the impact on climate change. Therefore, geology and stratigraphy of peatlands in Latvia, their origin and dynamics of peat accumulation were investigated. This information, in turn, gives understanding of the properties of deeper layers of residual peat in five areas which were studied in detail during the LIFE REstore project: Lauga Mire, Lielsala Mire, Kaigu Mire, Drabiņu Mire and Ķemeri Mire. It has been found that peat properties such as pH value and density have changed in the residual peat layer. Also peat composition has changed, including the changes in proportion of mineral matter. It can be explained by peat decomposition resulting from hydrological changes in peatland.

Introduction

Similarly to most part of Northern Europe, several factors contribute to the formation and development of peatlands in Latvia, including moderate climate characterized by higher precipitation than evaporation, slightly undulated relief, clayey, poorly permeable deposits in relief depressions, and hydrological regime. The set of climatic, hydrological and geological conditions determines that peatlands can develop in Latvia in two ways: by land paludification and by filling-in of shallow water bodies. All these factors contribute to the establishment and growth of peat-forming vegetation in wet depressions. When these plants decay, they form a layer of peat on which mire plants continue to grow and later form the next peat layer. Older layers of peat covering the younger ones form a kind of archive of geological events, vegetation and climate change that can be studied within peat stratigraphy[25].

Peat deposits are found throughout Latvia, but the distribution of peatlands is uneven. Also their age and prerequisites for their development are different in various nature regions (Figures 35, 36). Among other peatland types, raised bogs cover the largest areas and are located in Eastern Latvia Lowland, Coastal Lowland, Middle Latvia Lowland and North Vidzeme Lowland. Many mires have developed by overgrowing of shallow lakes or oxbow lakes. Mires also developed in lagoon depressions of the former development stages of the Baltic Sea. As a result of Littorina Sea regression and drop of sea level, shallow lakes and bays established, filled up with organic sediments, and developed into mires 3000–5000 years ago.

The intensity of paludification and mire development differs in various regions of Latvia. Mires can occupy between 0.1% and 40% of the region. The largest paludified areas are located in lowlands with slightly undulated relief, where the Quaternary deposits consist mainly of clayey sediments – till or glaciolimnic clays accumulated in glacial melting water basins. Mires formed in relief depressions above

25 Stratigraphy is a branch of geology concerned with the study of historical sequence, age, developmental character and distribution of the formation of layers of the Earth's crust, including peat.

glaciolimic clays occupy 10–15% of coastal areas along the Gulf of Riga and about 30–40% of the Lubāns Plain (Lācis, Kalniņa 1998).

In mire geological sections, various layers of deposits can be distinguished, with differing peat forming species and their degree of decomposition. These differences indicate on climate changes in particular region during the mire development, including an increase or decrease in average air temperature, precipitation, and water level fluctuations in water bodies (Silamiķele et al. 2010; Kalniņa et al. 2017).

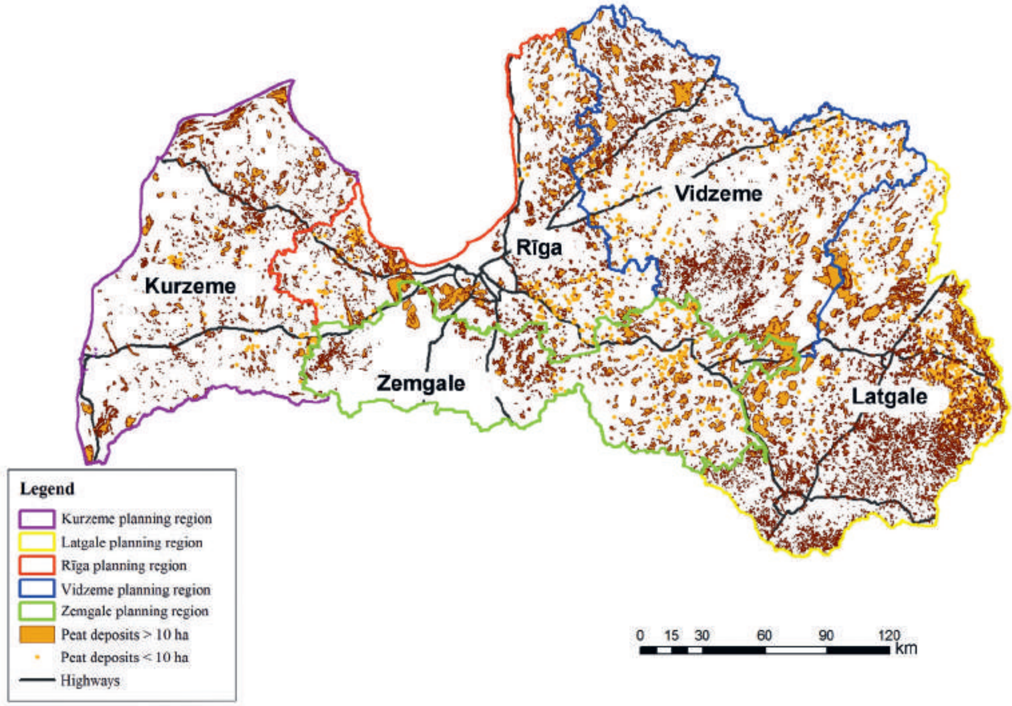


Figure 35. Distribution of peat deposits in Latvia. Source: Jansons (2016).

The oldest mires in the territory of Latvia started to develop in the Early Holocene, about 11,500 years ago, when the climate became warmer, vegetation developed, and biomass increased (Kalniņa et al. 2015). Mires developed in places where peat formation started due to paludification of water bodies or in wet depressions. Here, peat formation started after establishment of peat-forming vegetation. Usually it was fen peat in the early stage of mire. By studying mire peat cross-sections, it is possible to investigate climate change in the past, and to assess the intensity of climate change at the present time (Kalniņa 2008).

Nowadays, the areas, where peat has accumulated or is still accumulating, cover more than 10% of Latvia's territory. Although many of peatlands are overgrown with forests, or they are drained for agricultural use or for peat extraction, they form an important stage of water cycle in nature and affect the microclimate and hydrological regime of their surroundings (Nomals 1936). Of all Latvian cultural and historical regions, the largest mire areas occur in Latgale Region (3.4%). This is the region where mires cover the largest area as a percentage – 14.1% of the total area of the region. In Zemgale Region, the cover of mires is the lowest (1.46%). From Latvian natural regions perspective, the largest mire cover is in Eastern Latvia Lowland (~17%), North Vidzeme Lowland (~10.3%), Middle Latvia Lowland (~8.9%) and Coastal Lowland (~10.2%), where the largest mires and mire complexes are located (Kalniņa 2018a).

Over the last hundred years, the development of many mires has been halted by mire drainage (15% for agricultural use, 3.9% for peat extraction), and by overgrowth with forest, both naturally and in result of human activity. Peatland areas degraded by drainage were the study areas of LIFE REstore project. In these peatlands it was necessary to determine peat properties, and to choose the most appropriate complex of management measures for a reasonable use of land resources and for climate change mitigation. In order to choose the most appropriate management or reclamation methods for extracted or partly extracted peatland, it was important to clarify the origin of mire and its course of development. By ascertaining the residual peat and deposits below it, it is possible to clarify and explain under what conditions peat accumulation and mire development has started (Kalniņa et al. 2018). This, in turn, allows us to decide on the most suitable peatland management and reclamation measures, taking into account the research data and climatic conditions nowadays.

In order to develop recommendations for sustainable and responsible management and after-use of degraded peatlands in Latvia, it was important to investigate and characterize the stratigraphy of peatlands and the properties of peat in sections of the studied degraded peatlands. This chapter provides a general insight into the stratigraphy of peatland deposits in Latvia, using information from earlier studies, because understanding of mire formation and stratigraphy can only be obtained by studying larger number of peatlands. Thus, this particular study is a part of the overall picture. Further, data obtained in detailed studies in five demo sites of LIFE REstore project are analyzed. In the discussion part, they are compared with each other, as well as with data from previous studies. It helps to get a broader picture on changes of peat properties, and to choose the best reclamation measures in extracted peatlands.

Dynamics of peatland development

Environment and type of peat formation, age of peat layers, and the historical sequence of their accumulation are studied by peatland stratigraphy. Research results provide information not only on nature history and climate change during thousands of years, but also allow us to understand how to make better use of peatlands and how to improve peatland ecosystem functionality in degraded areas. These studies allow us to understand the importance of interactions between human, natural processes, and climate. Overgrowing of mires with forests occurred also in previous interglacial periods several hundred thousand years ago, when there were no or very few people, and their skills were poorly developed, so their impact on nature was negligible.

The character of relief and climate are the main factors contributing to the development of various mire types (fen, transitional mire, raised bog) in Latvia. Just half a century ago, it was believed that the largest areas of mires in Latvia are covered by fens (~50% of the total area of mires), slightly less – by raised bogs (42%), and the least – transitional mires (9%) (Latvijas valsts meliorācijas un projektēšanas institūts 1980). However, given that many of fens or their parts have been drained and therefore overgrown with forests during the last 40–50 years, or reached the development stage of transitional mire or raised bog, these proportions are no longer true (Kalniņa 2018a). Studies of peatlands show that the upper peat layers of mires are mainly composed by raised bog peat; however, fen peat is accumulated in the deeper layers above the mineral deposits or above sapropel. This shows that these mires initially developed as fens (Kalniņa 2008; Kalniņa et al. 2015).

Peatlands in the territory of Latvia have developed in the Holocene or post-glacial period which began 11,700 ± 99 cal. years ago (Walker et al. 2012). The Holocene includes climatic periods with characteristics that influenced the formation of mires, the intensity of peat accumulation, and the decomposition process and peat botanical composition. Comparing the models of peat accumulation intensity during the Holocene in Latvia, developed for mire sections where age was determined with at least three radiocarbon dating results, information on peat botanical composition and degree of decomposition was obtained (Kalniņa et al. 2015), showing general information on the course of mire formation and development, and an overview of mire stratigraphy in Latvia.

The first layers of peat began to accumulate in the beginning of the **Early Holocene or Preboreal**, about 11,500 years ago, when the climate was warm and humid enough for the development of moisture-loving plants. During this time, the oldest mires in the territory of Latvia started to develop, such as Rožu Mire and Vīķu Mire (Kalniņa et al. 2014) (Figure 36). The oldest peat deposits with known absolute age have been found in Rožu Mire – sedge *Hypnum* fen peat formed 11,490 years ago, and *Hypnum* fen peat formed in Vīķu Mire 11,088 years ago (Kalniņa et al. 2015; Kalniņa, Markots 2016).

Mires which are older than 10,000 years are usually formed by overgrowing of shallow water bodies (for example, Taurene Mire (10,555 years ago), Lazdienu Mire (10,455 years ago) and Eipuru Mire (10,337 years ago). In these mires, the lower layers of organogenic sediments consist of sapropel, which is lake (limnic) sediment, but are covered by mire deposits formed of fen peat (Kušķe et al. 2010; Silamiķele 2010; Kalniņa et al. 2015).

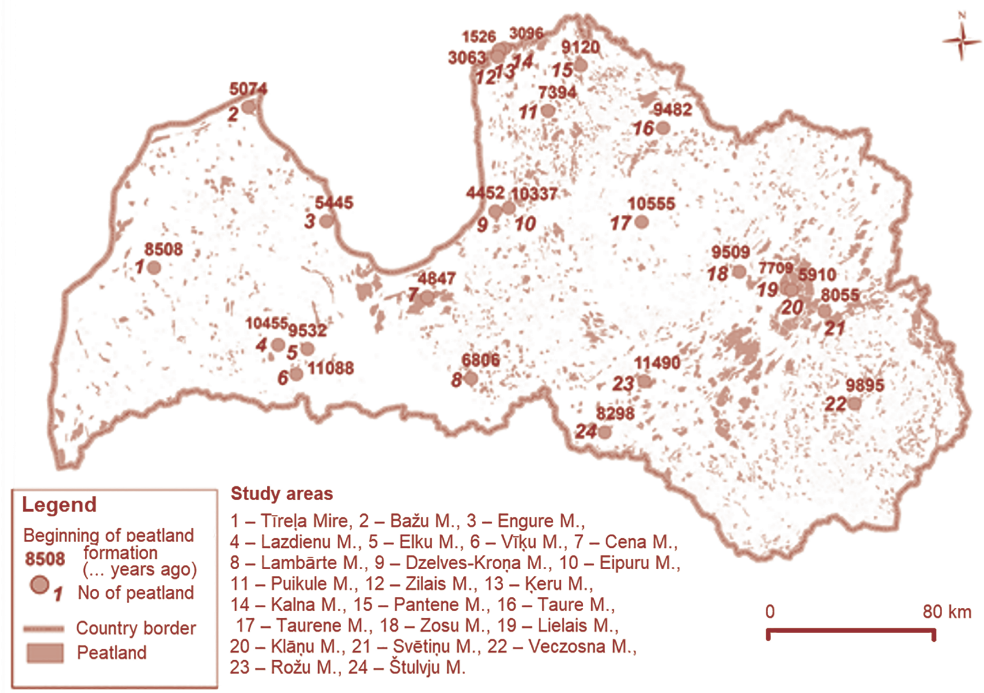


Figure 36. The beginning of mire formation in Latvia, according to the radiocarbon dating and age-depth modelling (after Kalniņa et al. 2015; Kalniņa Markots 2016).

In the relatively warm climate of the **second half of the Early Holocene, or Boreal (10,00–8200 years ago)**, not only development of new mires was enhanced (e.g. Ķemeri Mire, Kaigu Mire), but also the existing mires, such as Teiči Mire, became larger. As the thickness of peat layer increased, plants could no longer reach the mineral-rich groundwater, so the plant species of eutrophic habitats were gradually replaced by mesotrophic plants. *Hypnum* mosses and sedges *Carex* spp. were replaced by *Sphagnum* mosses and hare's-tail cottongrass *Eriophorum vaginatum*. There were few trees in mire depressions, mostly pines *Pinus sylvestris*, also birches *Betula* spp., black alders *Alnus glutinosa*. Few broadleaved trees grew at the edges of depressions (Kalnina, Markots 2004; Ozola 2013; Kalniņa 2018b).

In relief depressions, in the period of Ancylus Lake, and more markedly in the Littorina Sea period (stages of the Baltic Sea), the sea level rose and was about 5–6 m higher than nowadays. At that time, shallow lagoons emerged, which later, as the sea level dropped, developed into shallow freshwater lakes, which rapidly overgrew and transformed into mires. Groundwater levels increased in areas close to the sea coast, and peat deposits or sapropel began to accumulate in many depressions that previously were dry. Later, peat began to accumulate, and mires were formed, for example, Cena Mire (Kalnina 2007). Similarly, Kaigu and Drabiņu Mires developed. Here, similarly as in Cena Mire, layers of fen peat and transitional mire peat usually are no thicker than 1 m and are not distributed throughout the peatland area (Nomals 1930). In peat sections of these mires, the upper peat layer is 4–7 m thick and it consists of *Sphagnum* raised bog peat which has developed over the last 7000–4000 years since the beginning of Atlantic period (the Middle-Holocene).

In the **Middle Holocene or Atlantic period**, about 8200–4800 years ago, the climate gradually became warmer, and the average annual temperatures reached ~2.5–3.7 ºC above the modern mean annual temperature. The highest annual average temperature (from +3.0 to +3.7 ºC higher than nowadays) was reached during the Holocene Climate Optimum, 7500–5000 years ago. In the deepest depressions of many mires, there was already 2–3 m thick peat layer, and plants were fed only by precipitation. When they decayed, layers of raised bog peat developed. At mire edges, where the nutrient uptake of plants was mixed (precipitation and groundwater), layers of transitional mire peat and in some places also fen peat accumulated.

During the **Holocene Climate Optimum (Atlantic) period**, the climate was warm and dry, which contributed to better decomposition of plant remains, therefore a higher decomposition rate is characteristic for peat layers of this time (Kalniņa et al. 2015). In many large mires which had formed in the Early Holocene, but still belonged to fen type, vegetation changed. They gradually transformed into raised bogs, accumulating mainly *Sphagnum* peat and *Sphagnum*-cottongrass peat with wood remains. In dryer mire parts, pine woodlands and pine-cottongrass peat developed. During this time, peat layers in the large mires were already 1–2 m thick not only in their central parts, but also on edges of mire depressions. Mires grew rapidly both vertically and horizontally, and covered increasingly large areas (Kalniņa 2018b). Climatic conditions during the Atlantic period were favorable for the spreading of various plant species, especially for warmth-loving plants. Broad-leaved forests often grew in the surroundings of mires. This Climate Optimum period was favorable for the intensive development of mires, which is why it is marked as a period of rapid peat accumulation and higher peat decomposition. At the end of this period, *Sphagnum* species were widespread and dominated in raised bog vegetation.

Several mires developed by overgrowing of former shallow lagoons of Littorina Sea which were separated from the sea and became lakes when the sea level dropped. Nowadays in these depressions large mires are developed, for example, Sārnate Mire and Sloka Mire. Some of the coastal mires were later covered with wind blown sand, nowadays covered with wet grasslands, for example, in Melnsils (Pakalne, Kalnina 2005). Nowadays only the deepest of lagoon lakes have remained as lakes (for example, Kaņieris, Engure Lake, Babīte Lake, Sloka Lake), but mires also gradually develop on their shores.

About 4800 years ago, in the first half of the **Late Holocene**, climate change started, and climate become characteristic to Subboreal period – it was generally dry, and the average summer temperature was lower. Mire vegetation was dominated by *Sphagnum* (*Sphagnum magellanicum*, *S. fuscum*, *S. angustifolium*), *Eriophorum vaginatum*, *Scheuchzeria palustris* and dwarf shrubs; raised bog peat accumulated after dying of these plants. During Subboreal period (4800–2800 years ago) intensive peat formation continued in large areas. As thick layers of raised bog peat were accumulated, intensive formation of mire cupolas started, followed by breakage of peat layers under the influence of gravitational force, as well as formation of bog pools at the bases of cupolas and also on their flat top parts. For example, Melnā ezera Lake developed in one of the four cupolas of Cena Mire. Development of hummock-hollow mosaic micro-relief became more intense. Cracks at basal part of cupola naturally filled with water, and bog pools or hollows established (Markots et al. 1989; Namateva 2012).

In the **second half of the Subboreal period**, about 3500–2800 years ago, interdune mires started to develop in north-western part of Latvia, also in Slītere National Park, in a mosaic of dune ridges and interdune depressions (*kangari-vigas*) Initially mires developed in narrow interdune depressions (*vigas*) located between the dune ridges (*kangari*), where wet conditions prevailed and there was a shallow water body or water course. Here, grass fen peat or sedge fen peat started to develop. Later, when fen peat had already filled not only the depression but also covered the dune ridge, establishment of raised bog vegetation and formation of raised bog peat started. Peat layers of several interdune mires joined, and large massifs of raised bogs formed. Bažu Mire is a typical example of this type of mire development (Pakalne, Kalnina 2005; Kalniņa, Markots 2016).

In many raised bogs, the **boundary between Subboreal and Subatlantic** (between the first and the second half of the **Late Holocene**) is marked by intensive accumulation of slightly decomposed (3–8%) *Sphagnum* peat. At this time, about 2800 years ago, the climate became cooler and more humid. It contributed to rapid accumulation of low decomposed sphagnum peat (*Sphagnum fuscum* or *Sphagnum magellanicum*). Nowadays, the upper layer of many mires is composed of this peat type (Ozola 2013).

Marija Galenieks, a prominent Latvian botanist and mire researcher, characterized Subatlantic period as rapid climate deterioration, with decrease of temperature and increase of precipitation. Water levels in watercourses began to rise, and paludification processes intensified (Galenieks 1935). Research on changes in peat-forming plant composition shows that in the Late Holocene, despite the fact that climate gradually became cooler; there were several distinct fluctuations from cool to warm and again to cool climate. One of the most pronounced cold periods was the Little Ice Age. It lasted for about 330 years (1570–1900), when the summer temperatures in northern hemisphere (terrestrial areas north of 20º N) were significantly lower than average summer temperatures in 1961–1990 (Wanner et al. 2011). Little Ice Age and several other possible cold periods are well traceable in raised bog deposits formed during the Late Holocene and can be distinguished by very poorly decomposed raised bog peat (Ozola 2013).

During the last centuries (19^{th}–20^{th} century), the climate has been relatively variable, but in general conditions in mires were sufficiently wet, favouring the accumulation of poorly decomposed peat. The recent research study in Teiči Mire showed that over the past 150 years, peat accumulation on mire cupola slope reached 3.5 mm per year, while in other studied raised bogs in Northeastern Europe it has been on average 2 mm per year (Stivrins et al. 2017). In the last thousands of years, mostly *Sphagnum* peat has been accumulating in raised bogs. Often, remains of *Sphagnum fuscum* compose 45–90 % of the peat, and the rest consists of *S. angustifolium, S. magellanicum,* as well as *Scheuchzeria palustris*, *Oxycoccus palustris*, *Andromeda polifolia* and *Ledum palustre*. Remains of other plants are found in small quantities (less than 1%) (Kalniņa et al. 2014). This is due to the fact that many plant remains are rapidly decomposed (Dickinson, Maggs 1974; Лиштван 1996). By analyzing the results of both previous and recent research and calculating the rate of peat accumulation, it has been found that the most intensive peat accumulation has occurred over the past 2500 years.

In the oldest fens, the peat accumulation rate was higher in the beginning of their formation. For example, in Pantene Mire (Figure 37), 0.9 to 0.7 mm thick peat layer accumulated annually during the period 9750–7250 years ago. From nowadays (1950) to 7250 years ago, wood-grass fen peat layer accumulated above the fen-type grass peat. Its accumulation rate was lower and less variable, ranging from 0.4 to 0.31 mm per year (Ozola 2013). In the whole section, peat was well decomposed, and its decomposition rate changed from 35% to 45%.

A similar course of peat accumulation intensity was estimated in Taurene Mire (Vidzeme Upland, Piebalga Hillock) where peat decomposition rate in individual sections was 45–50% (Silamiķele 2010). The accumulation intensity of fen peat in lower part of Taurene Mire 10,300–9800 years ago has been 4.9–5.3 mm per year, but later it decreased significantly. Over the last 4200 years, peat accumulation became slower, up to 0.6 mm per year. It is possible that during some time periods it did not accumulate at all. The upper layers of these mires are characterized by a very slow peat accumulation which indicates on significant change in mire hydrological regime, a decrease of groundwater table and the intensification of decomposition of plants (Figure 37).

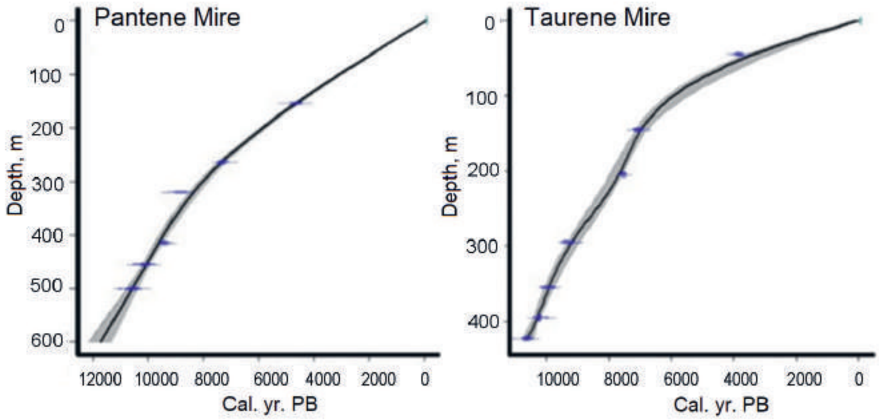


Figure 37. Curves of age-depth models characterizing the intensity of peat accumulation in fens – Pantene and Taurene Mires (Kalniņa et al. 2013).

Most of the raised bogs started their development as fens. With the change of plant nutrient uptake type and mire hydrological regime, and consequently the species composition of peat-forming plants, the accumulation of raised bog peat started. These mires are characterized by a low intensity of fen peat accumulation – 1–2 mm per year which increased to 6–12 mm per year during the accumulation of raised bog peat (Figure 38). The rapid increase in peat accumulation intensity is most often associated with low decomposition rate which often is within the range of 5–10%, indicating on high groundwater table and unfavourable conditions for decomposition of peat forming plants.

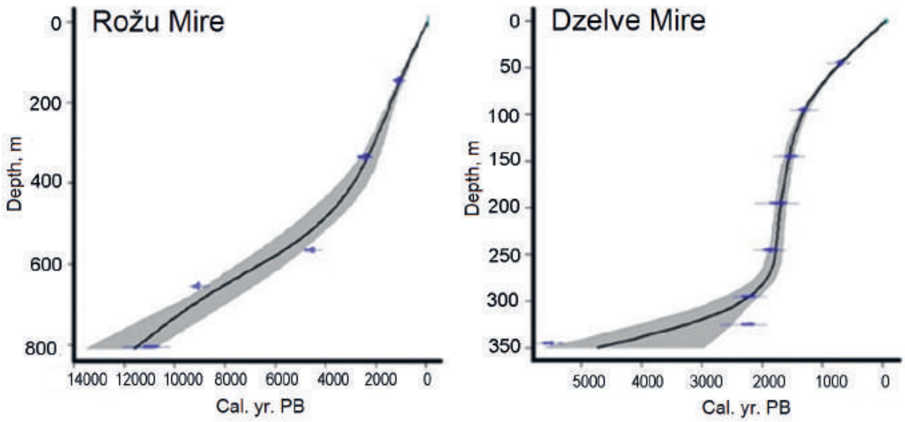


Figure 38. Curves of age-depth models characterizing the intensity of peat accumulation in raised bogs – Rožu and Dzelves Mires (Kalniņa et al. 2013).

Rapid development and peat accumulation is characteristic for mires which are located in lowlands. Here, in the last 2500 years, when the climate has become cooler and moister than during the Climate Optimum, on average even more than 10 mm thick layer of mostly poorly decomposed raised bog peat has accumulated every year.

Materials and methods

Study areas

In order to achieve the aim of LIFE REstore project – to develop recommendations for responsible and sustainable management of degraded peatlands – peatlands or their parts influenced by drainage or peat extraction were studied. The processes taking place in residual peat layers in such degraded mires were assessed and the changes of peat properties due to human activities were studied. Data from other studies with dating of absolute age from undisturbed mire sections, and data of complex investigation from full sections of mires (Ozola 2013; Kalniņa et al. 2015; Kalniņa, Markots 2016) were compared to the study of residual peat layers within the LIFE REstore project.

In order to get an overview on tendencies of changes in deeper peat layers in degraded peatlands, detailed studies were carried out in five areas of degraded peatlands: Lauga Mire, Lielsala Mire, Kaigu Mire, Drabiņu Mire and Ķemeri Mire (Figure 39). Every peatland is unique, therefore, in order to assess the changes of peat properties, also the undisturbed parts of mires were studied (Lauga Mire), or previous research data were used (Ķemeri Mire). In Lielsala Mire, properties of residual peat in three extracted peatlands in various locations of this deposit were studied to clarify if mire development conditions have been similar in the whole area. The analysis of data obtained in the study were interpreted and compared with data from undisturbed areas. This way, it is possible to conclude how the peat properties in residual layers have changed after drainage and peat extraction, and what is the thickness of residual peat layer.

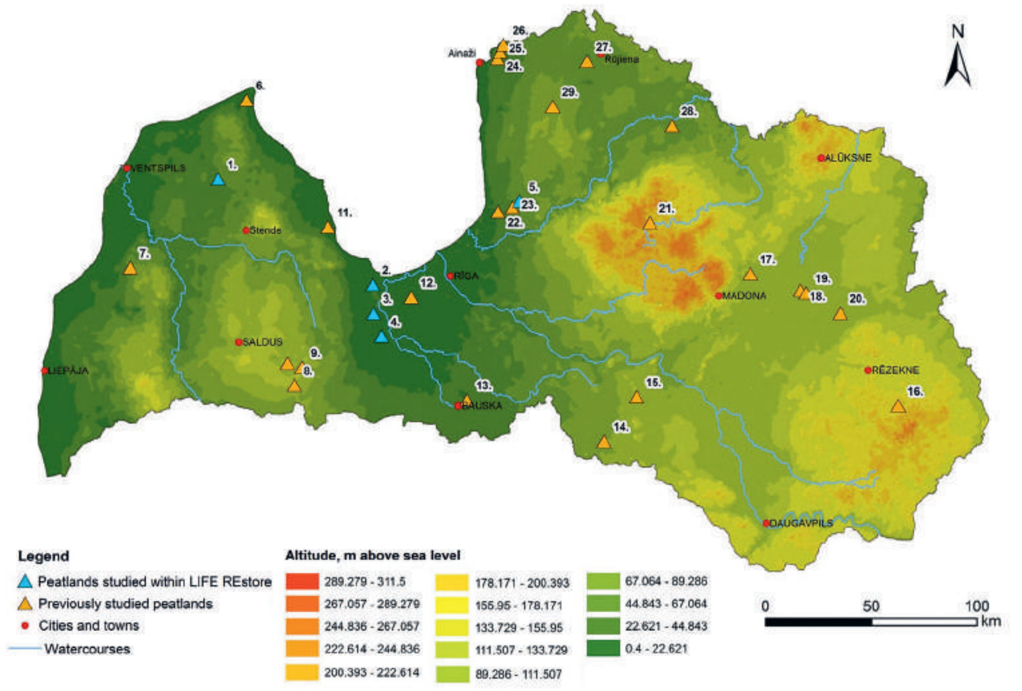


Figure 39. Location of mires studied within LIFE REstore project. Author of maps: R. Bitenieks.

Mires studied in detail in LIFE REstore project: 1 – Lielsala Mire, 2 – Ķemeri Mire, 3 – Drabiņu Mire, 4 – Kaigu Mire, 5 – Lauga Mire. Mires which were studied earlier, and the research data were used in this paper: 6 – Bažu Mire, 7 – Tīreļu Mire, 8 – Vīķu Mire, 9 – Elku Mire, 10 – Blīdene Mire, 11 – Engure Mire, 12 – Cena Mire, 13 – Lambartu Mire, 14 – Stulvju Mire, 15 – Rožu Mire, 16 – Zosna Mire, 17 – Zosu Mire, 18 – Lielais Mire, 19 – Eiņu Mire, 20 – Svētiņu Mire, 21 – Taurene Mire, 22 – Dzelve Mire, 23 – Eipuru Mire, 24 – Zilais Mire, 25 – Ķeru Mire, 26 – Kalna Mire, 27 – Pantenes Mire, 28 – Taures Mire, 29 – Puikule Mire.

Drabiņu Mire (Peat Fund No. 746 (Latvijas valsts meliorācijas un projektēšanas institūts 1980)) and **Kaigu Mire** (Peat Fund No. 874) are located in the north-western part of Tīreļi Plain, Middle Latvia Lowland, which borders with Nordeķu-Kalnciema dune ridge in the north-eastern part, and with Coastal Lowland in the north-western part. The undulating relief provides favourable conditions for paludification, resulting in mire development due to hindered groundwater runoff. Surface of the area is about 0.20–5 m above the sea level (TOPO 10K PSRS). Drabiņu and Kaigu Mires are raised bogs, and their development started about 8500 years ago, when groundwater table rose in their territories, and wet conditions favorable for mire plants developed. Drabiņu Mire developed in a shallow depression when wood-sedge-reed fen peat accumulated above the deposits of dense clay. Up to 5 m thick layer of poorly decomposed *Sphagnum* raised bog peat has accumulated above a relatively thin (about 1 m) layer of fen peat (Nomals 1930). The development of Kaigu Mire started about 9000 years ago, with accumulation of sedge-reed-*Hypnum* fen peat over the light gray carbonate clay (Nomals 1930).

The first study in Drabiņu and Kaigu Mires was carried out by Pēteris Nomals (Nomals 1930), a founder of mire research in Latvia. He created a geological section of these mires, giving an overview of the geological structure and characteristics of peat layers before the peat extraction (Kalniņa et al. 2017).

Peat is being extracted in Drabiņu Mire since 1930s. In 1947, Drabiņu Mire was studied in detail by Leningrad Peat Enterprises Design Institute, and in 1970 by the State Institute of Drainage Design. Nowadays, peat is extracted in Drabiņu Mire by SIA "Laflora".

In Kaigu Mire, boreholes (Figure 40.3) were located in western part of the mire, where peat extraction is completed and peatland is prepared for reclamation. In Drabiņu Mire, drillings are located in its central part, in peat field which is prepared for peat extraction (Figure 40.4). The purpose of coring was to investigate how peat properties are changing if peatland is significantly degraded (by drainage and topsoil removal) for a short time – about four years.

Ķemeri Mire (Peat Fund No. 806) is located in the Middle Latvia Lowland, Tīreļi Plain; its northeastern part borders with Coastal Lowland. It developed as mire on slope where the water flowed to the east; dense, poorly permeable clayey till deposits and underlying Upper Devonian dolostones forming the slope often created obstacles to water flow from south to the sea, causing water accumulation and wet conditions (Kalniņa, Markots 2004). At the same time, surface water flow closer to the sea was blocked by dunes of the Baltic Ice Lake. In the current mire area, waterlogged conditions formed, and mire formation began.

The beginning of Ķemeri Mire formation probably can be attributed to the temporary cooler climate, groundwater table rise and erosion. This is evidenced by admixture of sand and broken plant remains in fen peat. Before the Holocene Climate Optimum, various grasses, sedges, reeds grew in mire, and their remains formed peat. Pine forests grew in mire surroundings. During the Climate Optimum, at the beginning of Atlantic period, fen peat was covered by transitional mire type cottongrass-*Sphagnum* peat formed by plants which were both fed by precipitation and by groundwater (Pakalne, Kalniņa 2005). Milder and wetter climate caused rapid vegetation development, as well as biomass increase, accumulation of peat-forming plant remains and paludification.

Peat extraction in Ķemeri Mire was ceased in early 1980s. Several boreholes have been established in its undisturbed part (Kalniņa, Markots 2004; Pakalne Kalnina 2005), while boreholes in its disturbed part were established within LIFE REstore project (Figure 40.2).

Lielsala Mire (Peat Fund No. 175) is located in Kursa Lowland, northern part of Ugāle Plain, northern part of Venta-Usma depression. This area is characterized by flat to slightly undulated relief. The conditions for the formation of mire depression were determined by Venta Ice Lob, Venta Ice-dammed Lake and Baltic Ice Lake. Mires developed between the bedrock elevations, in depressions of unevenly accumulated plain in Ugāle Plain (about 20–30 m above the sea level) which initially were remnants of Baltic Ice Lake. Nowadays these mires are raised bogs which occupy large areas in Venta-Usma depression and form the complex of Stiklu Mires (Zelčs 2018). Also Lielsala Mire belongs to this complex. Its altitude above the sea level varies from 37.9 m to 40.8 m. The deposit consists of *Sphagnum* peat; the depth of peat is 2.6 m on average but can reach up to 6.0 m. Layers of transitional mire peat on average are 1.23 m thick. Fen peat is found only in some deeper depressions of mire and occupies small areas.

Peat extraction in Lielsala Mire was started in 1964. Currently, deposit is partly exploited. Since the 1990s, peat is being extracted by SIA „Pindstrup Latvija". Peat extraction was started in north-western part of the territory, which is located closer to the road. The first peat extraction fields (about 200 ha) were located close to bog edge, the peat layer was shallow (~2 m deep), and their extraction was completed in 1995–1997 (Cupruns et al. 2013). In order to clarify the thickness and properties of the residual peat layer, research was carried out in extracted fields in north-western part of the mire. Drillings were done in three peat fields where rehabilitation measures after peat extraction are already done (Figure 40.1).

Lauga Mire is located on the border between Coastal Lowland and Idumeja Upland, in southern part of Metsepole Plain, east of Bīriņi Ridge. Mire depression mainly consists of clayey till and glaciofluvial sediments. Lauga Mire is a raised bog. It is one of the largest mires in Middle Latvia Lowland, Metsepole Plain, with vegetation and micro-relief characteristic to raised bog, with bog lakes (Višezers and Lode Lakes) and bog pools. According to Peat Fund (No. 1827), 1980, the total area of Lauga Mire is 1876 hectares. Thickness of mire organogenic deposits reaches about 9 m; in the deepest layers peaty sapropel was found (in the depth between 0.8 and 1.3 m), covered by a 0.7 to 1.2 m thick layer of well decomposed peat of fen and transition mire. The upper deposit strata consist of poorly decomposed bog peat layers of various types. Peat extraction in Lauga Mire was started in 1965–1966. In 1989, about 10% of the Lauga Mire area was used for peat extraction or was prepared for peat extraction by topsoil removal and construction of field ditches. Boreholes were established in south-western part of the peatland, in three sites with various degrees of mire modification. Borehole "Lauga1" was established in place where the territory was prepared for peat extraction by topsoil removal and construction of drain network; borehole "Lauga2" – in undisturbed part of mire; borehole "Lauga3" – in disturbed part of mire, near the collection ditch (Figure 40.5).

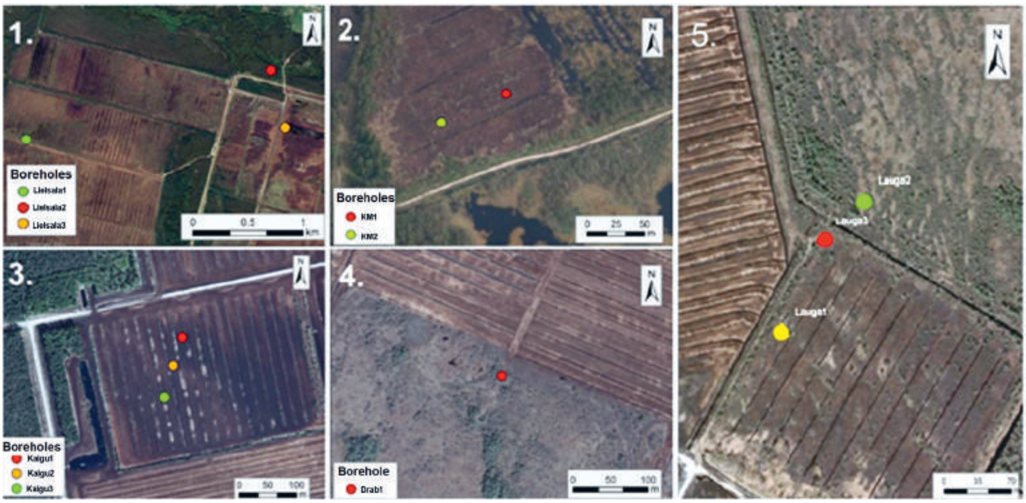


Figure 40. Locations of studied boreholes. 1 – Lielsala Mire; 2 – Ķemeri Mire; 3 – Kaigu Mire; 4 – Drabiņu Mire, 5 – Lauga Mire. Author of map: R. Bitenieks.

Field work

Study areas were surveyed, and field works were carried out in peat fields of Lauga, Lielsala, Kaigu, Drabiņu, and Ķemeri Mires. Peat monoliths were sampled for laboratory analysis. Test probing was carried out to find the most suitable place for detailed research. For geological coring, soft sediment corer was used. Sample monoliths were documented and prepared for transportation to laboratory. Eleven boreholes were established (Figure 40).

Laboratory methods

Peat monoliths obtained in boreholes were studied in laboratories of University of Latvia. Analysis included: loss-on-ignition analysis to determine the content of organic matter and ash; analysis of peat decomposition degree and botanical composition; peat pH values; peat density.

Loss-on-ignition analysis

Loss-on-ignition analysis is one of the most important methods for the understanding of the character of sediment composition. Its results allow us to find out the percentage of accumulated organic matter in peat-forming plants, carbonates and mineral matter in deposits. The total amount of carbonates and mineral matter characterize the amount of ash in peat. It is an important indicator for evaluation of the quality of peat as a product, and also for choosing the most appropriate reclamation measures. The content of carbonates and mineral matter in ash provides more specific information on peat suitability for growing of certain plant species.

Loss-on-ignition analysis is based on successive sample heating. At +550 °C, the amount of organic matter is obtained. At +900 °C, amount of carbonated matter is obtained. The remained material represents the amount of mineral matter. Loss on ignition analysis has been carried out in special furnaces, according to internationally approved methodology (Heiri et al. 2001).

Determination of degree of decomposition and botanical composition

Initially, the degree of peat decomposition was determined on field, immediately after sampling, using von Post scale (von Post, Granlund 1926; Landva, Pheeney 1980). However, this method is approximate, so the degree of decomposition was also determined in laboratory using light microscope and standard GOST 28245-89 (Издательство стандартов 1989) which has been developed and accepted for this region.

Peat decomposition degree is closely related to the amount of humic matter in peat mass. There is higher content of humic matter in well decomposed peat than in poorly decomposed peat. According to peat decomposition degree, three types are distinguished: poorly decomposed (decomposition degree less than 20%); moderately decomposed (20–30%); well decomposed peat (higher than 30%) (Latvijas valsts meliorācijas un projektēšanas institūts 1980; Šnore 2013).

The degree of peat decomposition is determined in order to understand how the deposit accumulation conditions have changed. Peat decomposition data is widely used to describe changes in the hydrological regime of peatland which can be caused both by climate change and by local influences including human activity. Higher degree of decomposition indicates on dry and warm climate; low decomposition – on wet and cool climate conditions (Charman 2002). If peat decomposition degree is higher, climatic conditions were drier at the time of its formation, compared to conditions under which less decomposed peat was formed (Nomals 1930). When choosing the reclamation methods, it is important to know the degree of peat decomposition, as it affects other peat properties, such as density, and can act similarly as aquitard with lower filtration than other peat layers. Depending on the characteristics of mire depression and the structure of peat layers, the hydrological regime in peatland (for example, groundwater inflow) can be influenced by such poorly permeable layer.

The diversity of ecological conditions forms an environment that, depending on the composition of plant remains and microbiological processes, creates peat with differing physical and chemical properties (Тюремнов 1976).

The analysis of peat botanical composition is important in order to accurately determine the peat type and the dynamics of mire vegetation (Тюремнов 1976). Determination of peat botanical composition is based on the macroscopic and microscopic features of peat, identifying the dominant plants that create composition of the sample. The analysis of peat botanical composition is carried out after the determination of peat decomposition degree. A small amount of peat is taken from several spots of fresh sample. For botanical analysis, plant particles which remain after a screening in 1 mm mesh sieve are used; they are examined and identified using binocular microscope with a magnification of 100 times (one field of vision is assumed to be 100%) (Издательство стандартов 1989). Species of plants, i. e. peat producers, are determined using various identification keys of plant macroscopic remains.

Peat botanical composition shows proportions of the remains of main peat-forming plants in the sample. This, in turn, is used to determine peat type and kind, depending on the percentage of peat-forming plants (Šnore 2013; Тюремнов 1976). The composition of peat-forming plants is an important parameter when choosing the reclamation method. For example, if the restoration of bog vegetation with *Sphagnum* is preferred, it is possible only if upper peat layer consists of *Sphagnum* peat. Fen peat is unsuitable for the growth of *Sphagnum* mosses.

Determination of peat density

Density of peat is the volume unit of peat mass expressed as kg/m3 or t/m3 (Šnore 2013). It depends on the peat type, degree of decomposition, humidity and ash content. Ash content can increase not only due to natural processes, but also due to human influence. Using the density as an indicator, it is possible to assess the depth of drainage influence in mire. Information on changes in peat density is important also when modeling groundwater flows.

Determination of peat pH value

Peat acidity or pH value is an important parameter characterizing the peat environment, and it is usually related to particular peat type. It is important to know peat pH value when choosing the reclamation method suitable for a particular peatland to know which plants can be reintroduced in the area, taking into account their habitat requirements. Peat pH value was determined in the laboratory of University of Latvia, Faculty of Geography and Earth Sciences, in solution according to ISO 10390, 2005. For all boreholes studied, pH values were determined in range of 20–50 cm, by evaluating the changes in sediment composition after analysis of loss-of-ignition (Krūmiņš 2012).

Results and discussion

Changes in peat properties in studied mires

The results of laboratory research characterize the properties of peat and allow us to conclude that the set of peat properties and their changes are interrelated. For example, when the degree of peat decomposition changes, also its density changes.

Composition of sediments

Based on the results of loss-on-ignition analysis, diagrams were created, showing separate zones that characterize deposit composition changes in the section, and allow comparing the character of the deposit composition and its changes both in the section and with other sections in the same or other peatlands. In the diagrams, loss-on-ignition zones I and II provide information on peat accumulation conditions at the beginning of mire development. In extracted peatlands, residual peat often consists of peat which is formed during the early stages of mire development, and its properties are very important for planning of reclamation.

Loss-on-ignition zone I is separated in the lower part of section, which usually has a predominance of mineral matter, which decreases in the upper part of section. This can be explained by the fact that the composition of peat which is deposited on mineral ground in the basal part of peatland, is influenced by mineral sediments and by groundwater flow. Their influence decreases in the upward direction, with increasing peat layer thickness. The ratio of organogenic and mineral matter may fluctuate within the range of the zone. For example, in sections "KM1" of Ķemeri Mire (Figure 41), and "Lauga2" (Figure 42), this indicates on significant changes in sediment accumulation conditions which are likely to be associated with changes in groundwater table, which in turn may be affected by climate conditions.

Loss-on-ignition zone II is separated in depth interval which is usually characterized by significant increase in the amount of organic matter and decrease in mineral content, which indicates stable peat accumulation conditions and mire development. Often, the percentage of carbonates in this range is increasing, for example, in section "KMI" of Ķemeri Mire (Figure 43). This is possibly related to leaching of carbonates and their transport from deeper embedded carbonate rocks or till rich in carbonate rocks. In sections where absolute age has been determined, this interval has most often accumulated in the second half of Early Holocene (8500–7500 years ago), when climatic conditions were favorable for carbonate dissolving and the till was still rich in carbonate rocks.

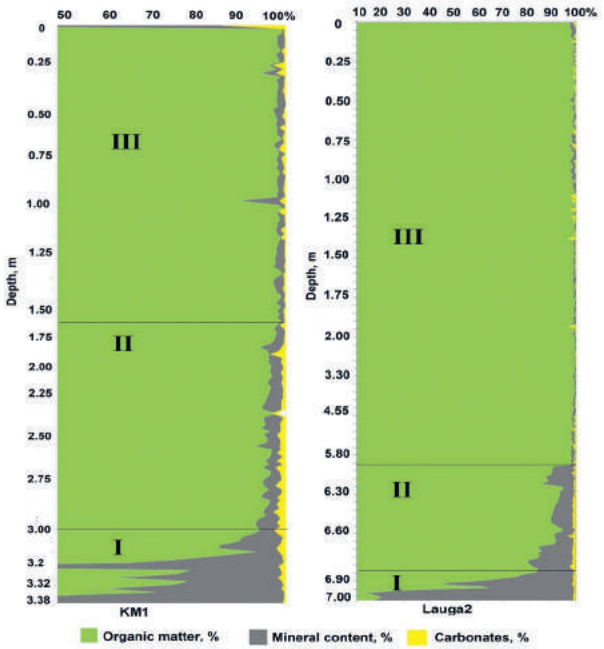


Figure 41. Changes in residual peat layer composition in section "KM1", according to results of loss-of-ignition analysis.

Figure 42. Changes in residual peat layer composition in the undisturbed part of Lauga Mire, in section "Lauga2", according to loss-of-ignition analysis results.

Loss-on-ignition zone III is usually separated in section interval where the amount of minerals and carbonates is the lowest throughout the section. There is a sharp increase in the percentage of mineral matter in small (0.1–0.2 m) depth interval in some sections. This indicates on short-term changes in climate conditions that could have an impact on both groundwater and surface water. This zone can most often be distinguished in sections of undisturbed parts of mires, such as “Lauga2” (Figure 42).

Depending on the thickness of peat layer, **loss-on-ignition zone IV** can be distinguished in the upper interval of some sections – where a significant increase in mineral content is observed. Most likely, this is the result of human influence and various natural processes. The most distinct increase in mineral content can be observed in areas where the residual peat layer is thin, or in vicinity of open peatlands, or in sandy areas or in drained territories. However, it should be taken into account that these areas have been drained, so that, when the peat layer dries and settles, the mineral content in this section interval increases, and erosion processes become more active.

For example, in studied cutaway peatlands in Lielsala Mire (boreholes “Lielsala1”, “Lielsala2”, “Lielsala3”) mineral content in deposit composition increases from 20% to 40% (Figure 43). However, such changes are not observed in deposits from borehole “KM1” in Ķemeri Mire. This is probably due to the fact that the groundwater table in this part of mire has not been lowered in the whole section, and field ditches are not so deep to reach mineral sediments below the peat layers (Figure 41). Meanwhile, the increase in mineral content in the upper interval of a section of an undisturbed part of the mire is explained by transfer of dust from adjacent peat fields where active operation occurs, for example, in Aizkraukle Mire (Pujāts 2012). This is evidenced also by significant changes in mineral matter content curve.

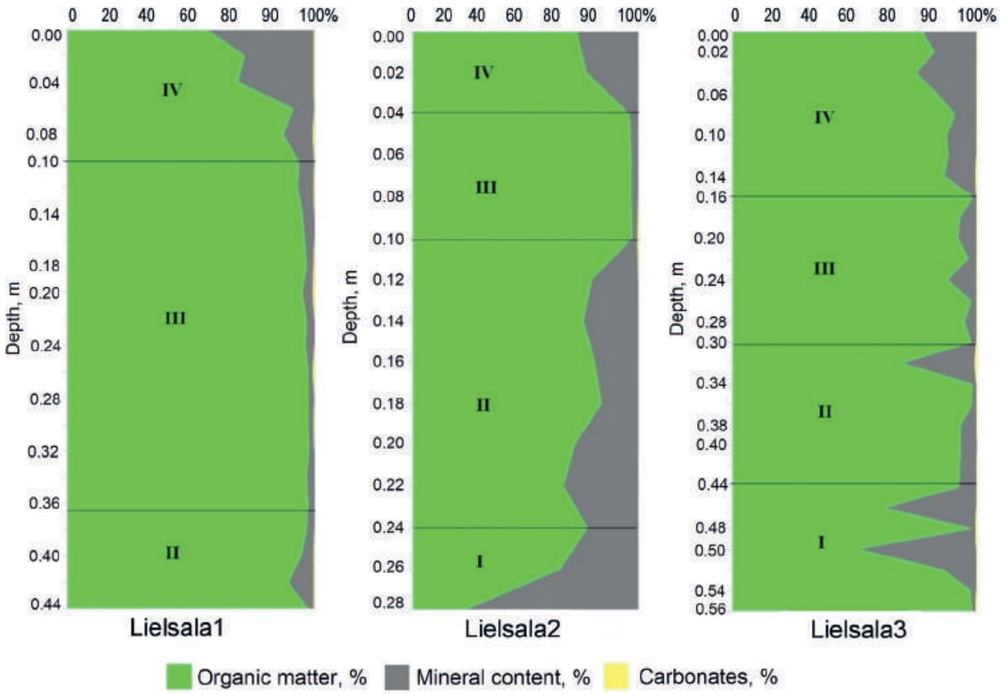


Figure 43. Changes in composition in residual peat layer (zones I–IV), according to data of loss-of-ignition analysis in different locations of Lielsala Mire.

Peat density

The results of peat density analysis (Figure 44) show that these values are fluctuating in the entire section of “KM1” (Ķemeri Mire). This indicates on a rather uneven distribution of peat density. At the basal part, the density fluctuates within 0.1 g/cm3. Density increases substantially in the middle part – from 0.93 to 0.97 metres. This may be explained by drainage that has affected the particular layer. Also, the results of loss-of-ignition analysis show increased amount of mineral matter in this interval in section “KM1” (Figure 41). The rapid increase in peat density is observed in lower part of sediments. This can be explained both by natural compaction due to weight of the deposit layers, and by loss of water in peat. The high density of peat can also be related to higher degree of peat decomposition and higher amount of mineral particles leached from mire bottom.

Similar changes in density are also observed in studied sections of Lauga Mire. In section from the intact part of mire “Lauga1”, density changes are small, and they increase significantly in section basal part. The highest density values were found in “Lauga1” and “Lauga3”, which are located in disturbed part of mire. This can be explained by drainage influence (Figure 45).

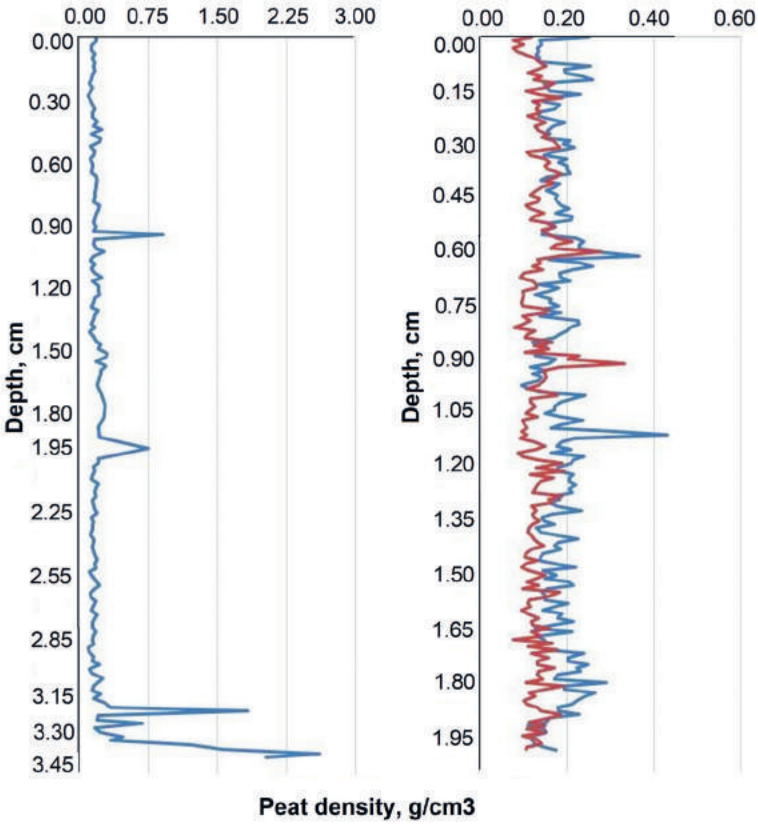


Figure 44. Peat density (g/cm3) in section “KM1”, Ķemeri Mire.

Figure 45. Peat densities (g/cm^3) in upper parts (0–2 m) of studied sections in Lauga Mire.

Peat pH value

Peat acidity (pH value) characterizes conditions of the formation of particular peat type. However, it is often influenced by various factors, including human activities. When comparing the pH values in sections of the studied peatlands, differences and deviations from the usually observed values were observed. When analyzing the classical mire development cycle from fen to transitional mire and to raised bog, the pH value changes from 5 to 7 in fen peat, and from 2.8 to 4 in raised bog peat (Nomals 1930; Rydin, Jeglum 2008; Тюремнов 1976; Маслов 2008).

Earlier studies in Kaigu and Drabiņu Mires have shown that the upper peat layer, which is up to 4–5 m thick, consists of poorly decomposed *Sphagnum* peat (Nomals 1930). Under the upper layer, moderately or well decomposed sedge-wood-*Hypnum* peat has accumulated; its pH value in natural conditions is higher than 4. In analyzed residual peat layer in section “Kaigu 1” (Kaigu Mire), which is composed of well decomposed transitional peat and wood fen peat, pH value changes from 4.5 to 5.5 (Figure 46). Upper part of section “Drab 1” (Drabiņu Mire), is composed of *Sphagnum* raised bog peat and cottongrass-*Sphagnum* raised bog peat. Here, pH value was rather high (5–5.5) which is not characteristic for raised bog peat. Taking into account that Drabiņu Mire borehole is located near the peat extraction fields, it can be assumed that the pH value here has been affected by drainage or by groundwater flows. The residual peat layer in extracted peatland in Kaigu Mire consists of all three types of peat: fen, transitional mire and raised bog.

Fluctuations of pH values in the entire section (Figure 47) indicate on fluctuations in mineral content and groundwater table. However, also in this section, pH value of raised bog peat (pine, pine-cottongrass and cottongrass-*Sphagnum* peat) was unusually high (> 5).

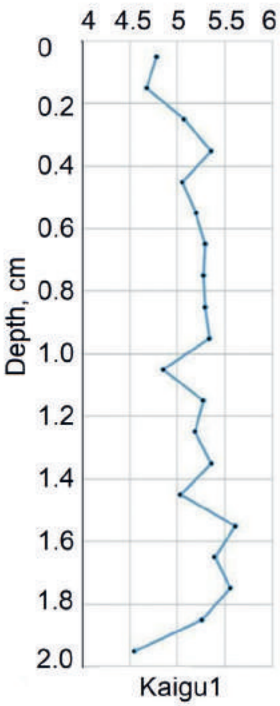


Figure 46. pH values in section ”Kaigu 1”.

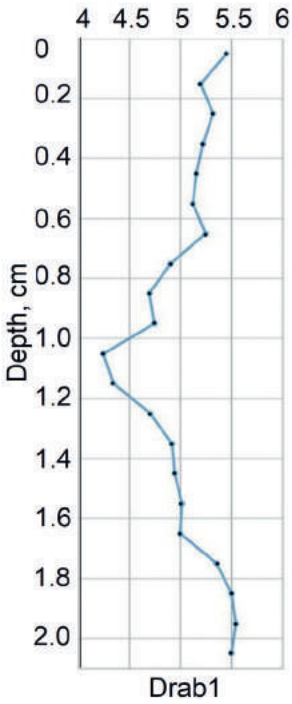


Figure 47. pH values in section ”Drab1 1”, Drabiņu Mire.

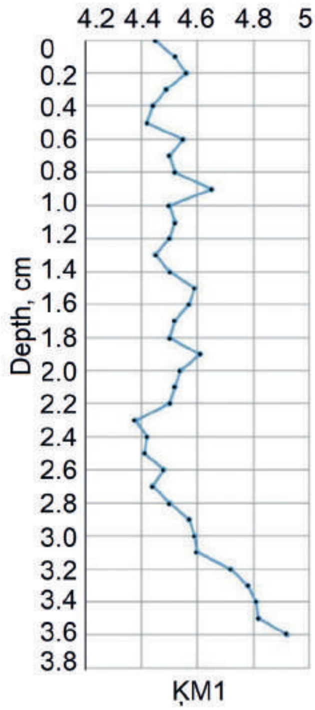


Figure 48. pH values in section ”KM1”, Ķemeri Mire.

In “KM1” borehole of Ķemeri Mire, pH value in upper part of the section changed from 4.8 to 4.9, which is characteristic to transitional mire or even fen peat. However, peat layer of this type is rather thin in Ķemeri Mire. In upward direction, decrease of pH value was observed (Figure 48). These differences were small, and pH value did not reach the level characteristic for raised bog peat which is typically below 4.

Similar pH values were also determined in “KM2” section, where in upper layer they varied from 4.3 to 4.1. In field works by LIFE REstore experts it was found that the thickness of residual peat layer in Ķemeri Mire is between 1.25 m and 1.65 m, but peat pH value varies from 4.83 to 5.97, which is even more unusual for raised bog peat. In lower part of the section (2.10–3.50 m deep), where fen peat is mainly accumulated, the pH values increase to 4.95, which is characteristic to fen peat.

Sections “Lauga1”, “Lauga2” and “Lauga3” differ in their degree of human impact, and here are few general trends in pH values (Figure 49). Trends of pH value differ, with exceptions: in interval 0–1.0, the average pH values (pH = 4.3) were similar in “Lauga1” and “Lauga2”; in interval 1.4–2.0, the average pH values (pH = 3.5) were similar in “Lauga2” and “Lauga3” (Figure 49). In “Lauga1” (located in the most degraded part of peatland) pH values increased with increasing depth, indicating that not only pH values of the upper layers are affected, but also that in the lower layers fluctuations can be observed. In “Lauga2”, despite the fact that it was located in the undisturbed part of mire, pH values in the upper interval of the section (0–1.0 m) varied from 3.5 to 4; but in interval from 1.0 to 2, pH values were lower and characteristic to peat of undisturbed raised bog (2.8–3.5). pH values in “Lauga3” section in interval 1.2–1.4 m remained unchanged, with few variations. Raised bog peat was found in upper interval (0–2.0 m) of all sections, and its pH values mostly corresponded to acidic values (3.12–4.86). Various pH values were found in sediments in the disturbed parts of mire, indicating on various drainage effects, which could possibly be associated with differing groundwater flow and peat properties.

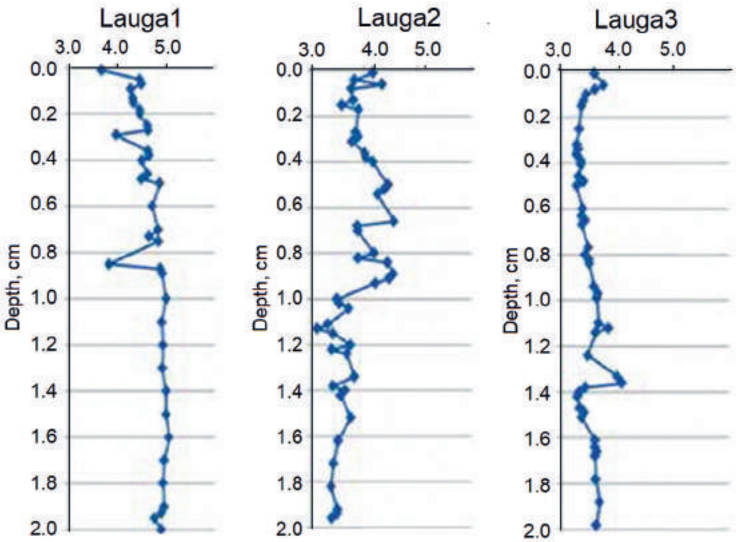


Figure 49. pH values in upper peat interval (0.0–2.0 m) of boreholes “Lauga1”, “Lauga2” and “Lauga3”.

At the margin of Lielsala Mire, large areas are occupied by extracted, rewetted peatlands. Depth of the residual peat layer is small (0.3–0.5 m). Results of peat pH analysis from three extracted peat fields show that acidity differs between the studied residual peat layers. It differs both in every individual section from bottom to top, and also between the sections (Figure 50).

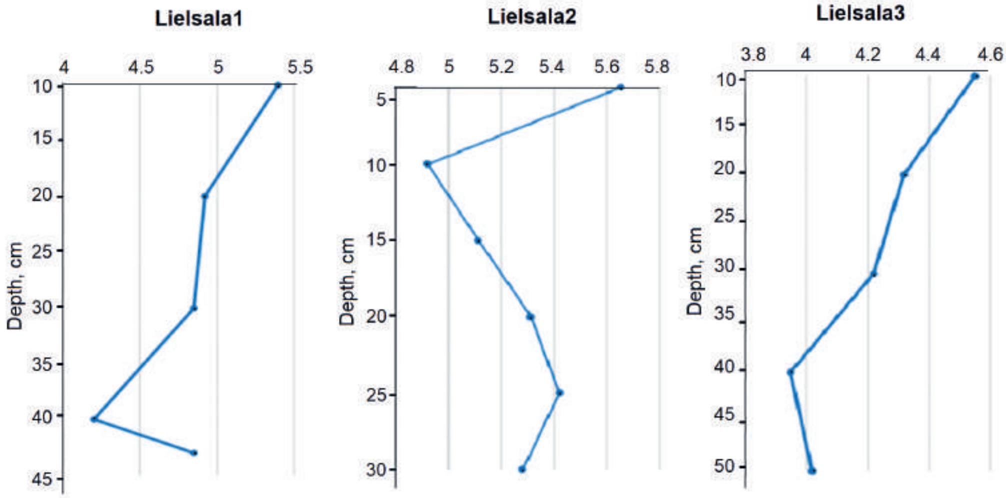


Figure 50. pH values in sections of “Lielsala1”, “Lielsala2” and “Lielsala3” boreholes.

Upper layers of sections of Lielsala Mire are composed of peat of various types. Their pH values are differing and often do not conform with values characteristic to particular peat type. In section “Lielsala1”, upper level consists of fen peat with pH value 5.34; in “Lielsala2” it consists of transitional mire peat, pH 5.65, and in “Lielsala3” there is raised bog peat, pH 4.55. pH values in these sections are influenced by both mineral content and increase of peat density due to drainage (taking into account the location close to mineral sediments of mire bottom).

Changes in peat botanical composition and degree of decomposition

Botanical composition and degree of decomposition are one of the most important characteristics of peat. Botanical composition and degree of decomposition depend on conditions of sediment accumulation and may vary according to the environment (Nomals 1930). Peat botanical composition characterizes the composition of plant remains that may differ from the current species composition in mire. At the end of vegetation season, plants die, are deposited and form current peat layer (Dickinson, Maggs 1974; Лиштван 1996). Diagrams show the composition of the main peat-forming plant remains, which is used for the determination of peat type and kind. This can be seen on the left side of the diagram, in the column called “lithology”, which means the composition of the sediment, and it is explained below, under the diagram.

In **Drabiņu Mire**, in peatland prepared for peat extraction, the upper (2 m) peat layer is composed of raised bog peat with variable decomposition rate and varying kinds of peat (Figure 51). Low decomposed *Sphagnum fuscum* peat (13–16%) reaches 65% in the section interval from 130 to 135 cm, and 13% in upper part of the section, in an interval from 30 to 35 centimetres. In section intervals between 85 and 90 cm and between 175 and 180 cm, the amount of *Sphagnum fuscum* decreases to 25%, but cottongrass *Eriophorum vaginatum* is increasing, reaching 30–35% (Figure 51).

Taking into account the interrelationship between the main peat-forming plant remains in this layer, it has been concluded that cotton-grass raised bog peat has accumulated in these intervals. Throughout the section, there are also remains of *Sphagnum angustifolium*, *Scheuchzeria palustris*, and *Oxycoccus* spp.

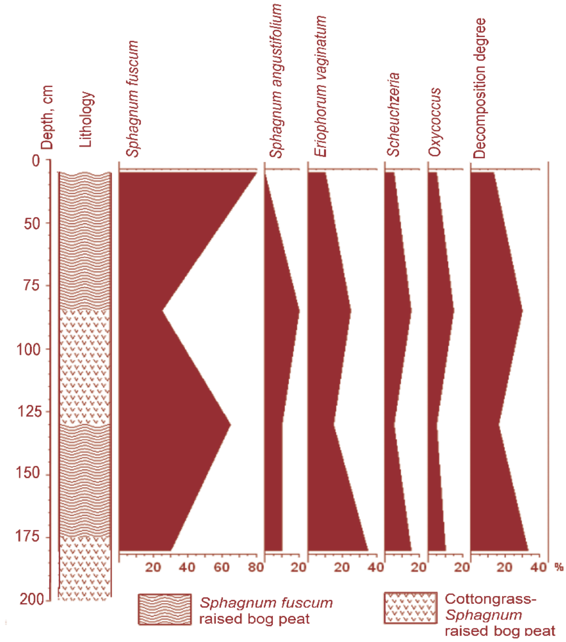


Figure 51. Botanical composition and peat decomposition degree in Drabiņu Mire, borehole "Drab1".

The base of **Kaigu Mire** below the extracted peatland is uneven. Therefore, the thickness of residual peat differs even at a small distance, and its changes from 0.75 to 1.95 metres were observed. The lower part of the section (1.90 to 1.75 m) consists of well decomposed (50%) wood-fen peat with a significant sand admixture. Most of it consists of *Pinus* wood remains (75%). Also remains of *Betula* and *Alnus* can be found, as well as *Dryopteris* and *Scirpus lacustris* (Figure 52).

Section "Kaigu3" is located about 100 m from "Kaigu1", and both sections are similar in botanical composition and decomposition degree (Figures 52, 53). Their upper layer consists of *Sphagnum*-cottongrass raised bog peat. In "Kaigu1", it can be found up to a depth of 1.7 m; transitional mire peat is located below it. In "Kaigu3", wood-fen peat is found already at 90 cm depth. In both sections, there is a significant amount of tree remains, especially pines. This indicates that in time of formation of these peat layers, there were bog woodlands in the area of Kaigu Mire, and there were also suitable conditions for growth of *Sphagnum* and cottongrass.

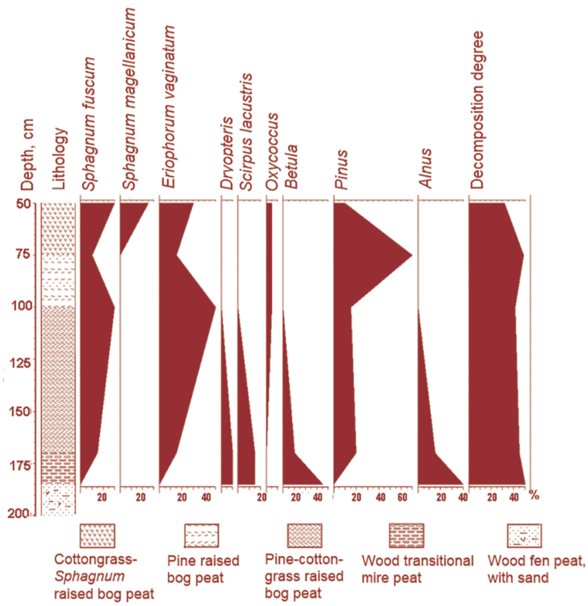


Figure 52. Botanical composition and peat decomposition degree in Kaigu Mire, borehole "Kaigu1".

"Kaigu3" griezuma, kas atrodas apmēram 100 m attālumā no "Kaigu1" griezuma, kūdras botāniskā sastāva un sadalīšanās pakāpes analīze uzrāda līdzīgus rezultātus (52., 53. attēls). To augšējo slāni veido augstā purva tipa spilvju-sfagnu kūdra. Tā "Kaigu1" griezumā sastopama līdz pat 1,7 m dziļumam, kur zem tās ir pārejas purva tipa kūdra, bet "Kaigu3" griezumā jau 90 cm dziļumā konstatēta zemā purva tipa koku kūdra. Abu griezumu kūdras slāņu sastāvā ir ievērojams daudzums koku, sevišķi priežu atlieku. Tas liecina, ka, veidojoties šiem kūdras slāņiem, Kaigu purva teritorijā ir bijuši purvaina meža apstākļi, kurā ir bijuši labvēlīgi apstākļi arī sfagnu un spilvju augšanai.

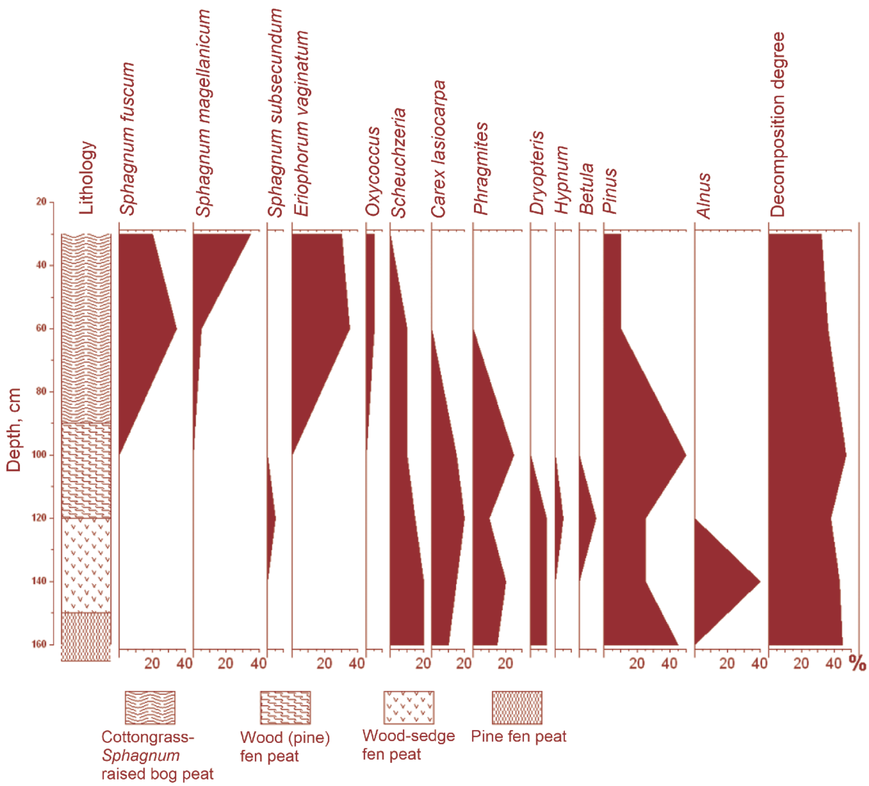


Figure 53. Botanical composition and peat decomposition degree in Kaigu Mire, borehole "Kaigu3".

In section "Kaigu1", above the fen peat, well decomposed (45%) wood peat of transitional mire has accumulated. In its composition, the proportion of wood decreases to 45%, and cottongrass and *Sphagnum fuscum* increases up to 15%. Upper part of the section (1.1 m) is composed of raised bog peat. It includes pine and pine-cottongrass peat in interval of 1.1 to 0.55 m, and cottongrass-*Sphagnum* peat above 0.55 metres.

By analyzing residual peat layers in Kaigu Mire, it can be concluded that in early stages of mire development, all three types of peat (Kaigu1") have accumulated, but in some places also raised bog fen peat have accumulated directly on top of fen peat. It indicates that the there has not been significant groundwater supply, and plants were fed by precipitation. Peat is well decomposed in all layers (over 40%), except for the upper cottongrass-*Sphagnum* layer where decomposition degree was lower than 32%.

In the partly extracted peatland of **Ķemeri Mire** (borehole "KMI"), thickness of residual peat layer is 3.4 m (Figure 54). The lower part of the section (2.30–3.35 m) consists of well decomposed (31–37%) fen peat of sedges and reeds. Well decomposed (31–37%) wood-grass transitional mire peat has accumulated above it (Figure 54). Botanical composition of wood-reed peat and reed peat is dominated by *Phragmites australis* (45%). In sedge peat, remains of *Carex lasiocarpa* prevail (45%).

Fen peat (at 2.6 m depth from the residual peat surface) is covered by a well decomposed 25 cm thick layer of wood-grass peat. In its composition, sedges are abundant, including *Carex lasiocarpa* (20%) and *Carex elata* (10%); remains of *Sphagnum fuscum* indicate on changes in plant composition during the formation of this layer.

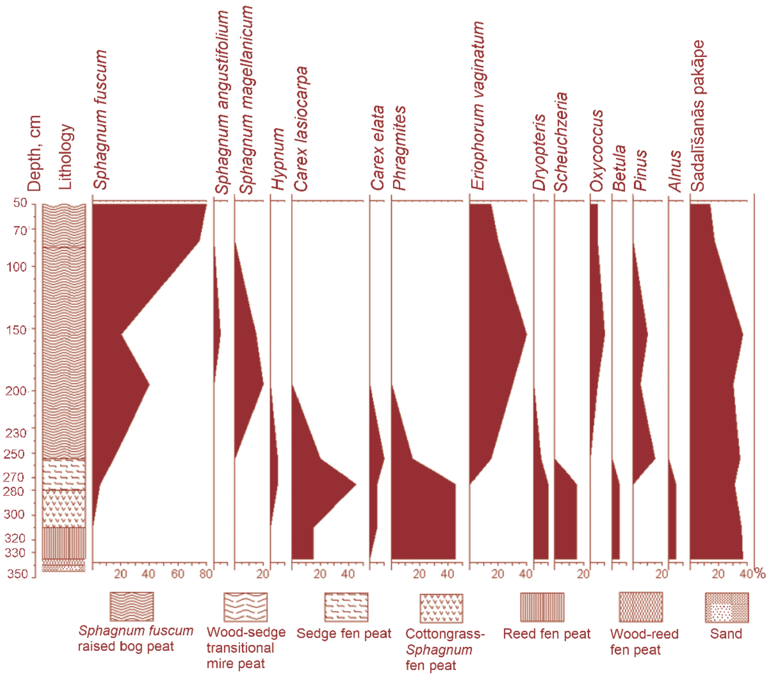


Figure 54. Botanical composition and peat decomposition degree in Ķemeri Mire, borehole "KM1".

The upper 2 m in section "KM1" consist of raised bog peat with varying degree of decomposition. Cottongrass-*Sphagnum* peat is well decomposed (37%). Upper part of the section (0–1.0 m) consists of poorly decomposed (14–17%) *Sphagnum fuscum* peat. Similar botanical composition of peat was observed also in section "KM2" where only poorly to moderately decomposed *Sphagnum fuscum* raised bog peat was found.

When comparing botanical composition and peat decomposition degree of section "KM1" with previous research of a whole section in northern part of **Ķemeri Mire** (near the observation tower at the bog trail) where total peat depth was 6.3 m (Pakalne, Kalnina 2005), it can be concluded that the upper, about 2–3 m thick layer in Ķemeri Mire is composed of *Sphagnum* raised bog peat. It also forms the upper layer in peatland degraded by peat extraction, where it reaches 2 m depth. Thus, it can be concluded that the depth of the extracted layer is small, or that extraction in the studied peat field was not done at all.

In **Lielsala Mire**, botanical composition was analysed in three locations of the extracted peat fields; they were relatively distant from one another because the mire covers a large area, and, first of all, peat was extracted closer to peatland margins and roads.

Botanical composition of residual peat layers indicate on differences in plant species composition that forms peat layer in different parts of mire, and on differences in their decomposition degree. The degree of peat decomposition in core section "Lielsala1" varied from 33% in the sample from deeper layer to 35% in the upper layer (Table 14). The increase in decomposition degree could be influenced by drainage. After extraction, when peat formed the upper level of section, it was influenced by compaction, oxidation and reduction.

In "Lielsala1" borehole, sediments are is composed of wood-grass fen peat. In greater depth than 45 cm, there is a substantial admixture of mineral particles, as it has formed above the bottom of sandy mire bottom. In both samples, peat is dominated by fen vegetation dominated by *Scheuchzeria palustris* and *Carex lasiocarpa*, and also residues of pines and alders.

In borehole “Lielsala2” peat layer is formed by wood-grass transitional mire peat, dominated by remains of *Eriophorum vaginatum* (Table 14). Plant remains are very well decomposed (44–48%), and therefore their identification was difficult. They are mixed with sand, which suggests that in this part of mire, as well as in borehole “Lielsala1”, peat may have been buried.

The sediment composition of “Lielsala3” borehole differs significantly from the previous ones. It consists of raised bog peat; poorly decomposed (30%) *Sphagnum fuscum* peat in the deeper layer and pine-*Sphagnum* peat in the upper layer. The whole section is dominated by remains of *Sphagnum* (55–85%).

Residual peat layers in extracted peatlands in Lielsala Mire are composed of peat of various types and various decomposition degrees. This is largely influenced by factors which determined the early development stages of the mire. In large mires, such as Lielsala Mire (1958 ha), these conditions may differ. It is possible also that deeper peat layers in the mire section are of different ages.

Table 14. Botanical composition of peat in the studied core sections of Lielsala Mire.

No	Depth, cm	Degree of decomposition, %	Botanical composition	% of total composition of remains	Peat type and kind
Lielsala1					
1	0.25–0.30	35	*Pinus* *Alnus* *Carex lasiocarpa* *Scheuchzeria* *Phragmites*	10 15 30 35 10	Wood-grass fen peat
2	0.45–0.50	33	*Pinus* *Alnus* *Carex lasiocarpa* *Carex riparia* *Scheuchzeria* *Phragmites* *Equisetum* *Hypnum*	5 10 20 10 20 15 10 10	Wood-grass fen peat with admixture of fine sand
Lielsala2					
1	0.10–0.15	44	*Pinus* *Alnus* *Eriophorum vaginatum* *Carex lasiocarpa* *Hypnum*	5 10 70 10 5	Wood-grass transitional mire peat
2	0.30–0.35	48	*Pinus* *Alnus* *Sphagnum fuscum* *Eriophorum vaginatum* *Carex lasiocarpa* *Dryopteris*	10 20 10 40 5 15	Sandy wood-grass transitional mire peat
Lielsala3					
1	0.25–0.30	30	*Pinus* *Sphagnum fuscum* *Eriophorum vaginatum* *Oxycoccus*	15 55 20 10	Pine-Sphagnum raised bog peat
2	0.35–0.40	12	*Sphagnum fuscum* *Eriophorum vaginatum* *Oxycoccus*	85 10 5	Sphagnum fuscum raised bog peat

In borehole "Lauga1" of **Lauga Mire**, botanical composition and decomposition degree of peat were analyzed only in the upper interval between 0.0 and 2.0 metres. This was done to find out whether there has been a change in peat properties since the peatland was prepared for peat extraction several years ago (topsoil removal, drainage). Results were compared to data of "Lauga2", evaluating the differences and similarities in the course of mire development in different places of the mire. In the entire section of borehole "Lauga1", *Sphagnum fuscum* is the main former of peat; it dominated in all of the studied samples (65–80%). The only exception was the interval from 1.0 to 1.2 m, where the amount of *S. fuscum* decreased to 35%, whereas *S. angustifolium* dominated (Figure 55).

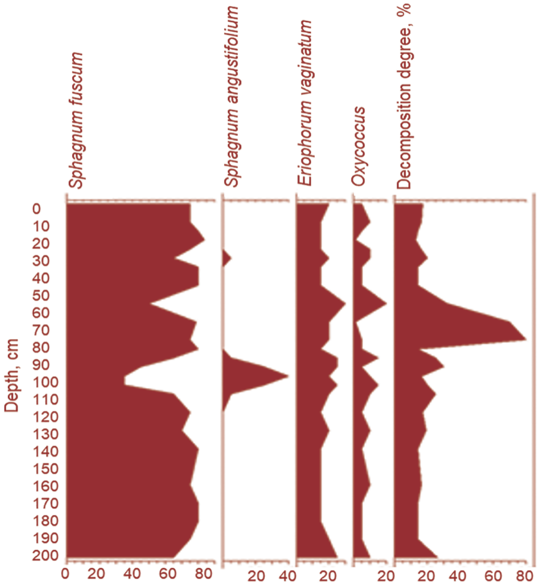
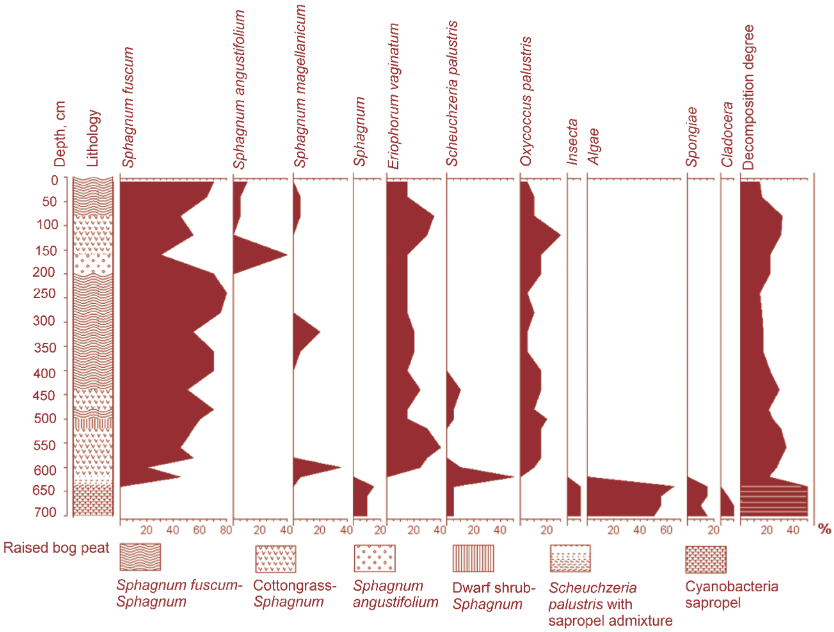


Figure 55. Botanical composition and peat decomposition degree in upper part of peat core section "Lauga1".



56. attēls. Kūdras botāniskā sastāva un sadalīšanās pakāpes diagramma urbuma „Lauga2" griezumā.

At the interval of 0.02 to 2.0 m in peat core section "Lauga1", peat was mostly poorly decomposed (13–17%), except at a depth of 0.55–0.98 m, where it was well decomposed (degree of decomposition reached 32%). This indicates on temporarily drier conditions and lower groundwater table that enhanced plant decomposition. In field studies at various locations of the Lauga Mire, the largest peat depth (6.4 m) was in found borehole "Lauga2" which is located in the undisturbed part of the mire where peat has accumulated on lake sediments (Figure 56). The deepest part of the core section "Lauga2" in the interval of 7.0–6.4 m consists of sapropel. Its composition is dominated by cyanobacteria, mainly *Lyngbya* (40%), slightly less by *Anabaena* (5%). The sediments also contain green algae (5–10%), mainly represented by *Scenedesmus* (5%) and *Botrycoccus* (5%), and also animal remains were identified (Insecta, Spongiae, Cladocera), 10% in total.

In a section of Lauga Mire at a depth of 6.4–6.2 m, *Sphagnum-Scheuchzeria* raised bog peat has accumulated above the sapropel layer, which does not correspond to mire formation cycle because fen peat is usually formed above the sapropel. After additional control analysis, it was concluded that in this layer *Sphagnum* (50%) and *Scheuchzeria* (50%) are equally represented. Most of the *Sphagnum* consists of *Sphagnum fuscum* remains (45%), although also remains of *Sphagnum magellanicum* were found. The admixture of sapropel indicates on water table fluctuations during the accumulation of this layer. Perhaps it can be explained by the formation of bog cupola and sliding of raised bog peat layers. In upwards direction in the section, only raised bog peat has accumulated, which is moderately decomposed up to 4 m from the mire surface (20–31%), and poorly decomposed (13–20%) above 4 metres. The exception is in interval from 0.8 to 2.0 m, where the degree of peat decomposition is higher, reaching 22–31%, indicating on drier conditions during peat formation. Cottongrass-*Sphagnum* and *Sphagnum angustifolium* raised bog peat have formed within this interval; in its composition, similarly as in the whole section above 6.0 m, remains of *Sphagnum fuscum* (50–80%) are dominating. An exception is the 1.4–2.0 m interval, where the amount of remains of *Sphagnum angustifolia* significantly increases and dominates (40%), while the amount of *Sphagnum fuscum* decreases to 30%. Such a layer with dominance of *Sphagnum angustifolium* is also evident in borehole "Lauga1" in the interval of 1.0–1.2 metres and is traceable in a wide area of this mire. Considering the ecological requirements of *Sphagnum angustifolium* (growing in drier conditions than *Sphagnum fuscum*), it can be assumed that the climate has been slightly drier during the formation of this layer. *Sphagnum angustifolium* as a peat-forming species has not been detected either above or below this distribution layer in both of the studied Lauga Mire sections.

Comparing botanical composition and the degree of peat decomposition of both studied boreholes in Lauga Mire, it can be concluded that the tendencies of sediment accumulation in the 0.0–2.0 m range of the upper layers have been similar. There were no significant differences, despite the fact that borehole "Lauga1" was located close to the mire margin affected by drainage. In this interval of both sections, only raised bog peat was found, but the decomposition degree differed. In "Lauga1" section it was poorly decomposed, and it was moderately decomposed in "Lauga2", which indicates that conditions were more humid and groundwater table was higher in the marginal area of the mire. It means that plant remains were covered with water without oxygen supply, and bacteria were not able to decompose plant remains.

Conclusions

- ✔ Every mire is unique, but in large mires their parts may differ from each other. Peat accumulation in each part can be influenced by geological processes and microclimate conditions. This means that if the mire area is larger than 100 ha, its structure and conditions cannot be evaluated by examining only one part of peatland and assuming that it characterizes the whole area.
- ✔ After peat extraction, peat properties in residual peat layer have changed. Mainly it has affected pH value, increased peat density, changed peat composition, including fluctuations in amount of

mineral matter which can be explained by peat decomposition due to changes of groundwater table. In some cases, an increase of peat density was observed in the upper part of the sediment section where peat was drier and more compacted. Often, pH values in upper peat layers of degraded peatlands do not correspond to pH values of the particular peat type, which indicates a change in environmental conditions due to various influences.

- ✔ Changes in mineral content and carbonate content indicate on changes in sediment accumulation environment – on influence of groundwater which likely introduced carbonates and mineral matter into peat layers.
- ✔ In areas degraded by peat extraction, where residual peat layer is several metres thick, changes in peat composition can be explained mainly by natural processes. Higher proportion of mineral matter in deeper parts of peat sections is determined by the fact that peat has accumulated on mineral ground, and it is influenced by minerogenic sediments and by groundwater flow.
- ✔ In peatlands degraded by peat extraction, decomposition rates of peat sediments are similar, and vary between 15% to 35%. This shows that the upper layer is composed of slightly or moderately decomposed peat. In some cases, changes in this indicator are associated with erosion.

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4.2. Geological inventory of areas affected by peat extraction

Laimdota Kalniņa

Summary

An inventory of 78 areas affected by peat extraction was carried out during LIFE REstore project, in order to obtain information on the following parameters, such as properties of the residual peat layer, depth of residual peat layer, mineral ground in the bottom, hydrological regime in the peatland. It was found that more than ten extracted peatland areas with a residual fen peat layer with depth less than 0.6 m would be suitable for the establishment of perennial grasslands, cultivation of paludicultures (reed *Phragmites australis*, cottontail *Typha spp*., reed canary grass *Phalaris arundinacea*), arable land and afforestation after the improvement of drainage system. In contrast, peatlands of residual raised bog peat, with peat layer depth between 0.3 m and 7 m, with poorly (5–20%) or moderately (20–30%) decomposed peat, mostly with high groundwater table, and low peat pH value (≤ 5) are suitable for re-creating mire conditions, cultivation of berries or *Sphagnum* mosses. Of all the peatlands surveyed, the establishment of water bodies would be a suitable after-use scenario in seven areas.

Of the 78 peatlands surveyed, more than 1.9 m thick peat layer was found in 21 raised bog type peatlands and 12 fen type peatlands. These areas are suitable for rehabilitation as well as for cultivation of plants for which a higher peat layer thickness is not a limiting factor. However, in order to ensure efficient use of peat resources, in areas where peat thickness is sufficient for extraction to be economically viable, and which are already affected by peat extraction, peat extraction may be the best way of further use, and then the areas should be reclaimed.

The results of inventory characterize the degraded areas affected by peat extraction and allow making reliable decisions about further use of these territories and the most appropriate reclamation methods.

Introduction

The earliest records about peat extraction in Latvia date back to the second half of 17th century and early 18th century when Duke Jacob issued an order that peat should be used as a fuel together with firewood. At that time, the first articles on peat extraction and its use as fuel and for agricultural purposes were also published (Šnore 2013). More extensive research on mire deposits started in 1912 when Pēteris Nomals, the founder of mire research in Latvia, was appointed as head of the Mire Research Laboratory of the Baltic Hydrotechnical Department under the Ministry of Agriculture of Russia. Shortly before World War I, peat was extracted in 324 mires in Latvia, in 48 of these mires peat harvesting was mechanized (Lācis 2010; Kalniņa, Markots 2016).

Between World War I and World War II, peat research in Latvia became more intensive. Peat was used for litter, heating and soil improvement. The importance of the peat extraction industry in the economy is evidenced by the fact that by 1940, 13 national peat factories were built, mainly for litter production. During this time, peat extraction was usually mechanized, while peat cutting, drying and collection were done manually (Nomals 1944). After World War II, the demand for peat increased in energy production and agriculture. From 1940 to 1980, 57,476.3 ha of peatlands were designated as peat extraction area, although the actual peat extraction took place in an area of 23,309 hectares. Block-cutting areas covered 734 ha (mainly cut manually), while vacuum harvesting took place in 22,575 ha (Šnore 2013).

Nowadays, peat is fully extracted in some of the peat deposits, or they are abandoned because of political change and change of land ownership. The objective of LIFE REstore project was to carry out an inventory of areas influenced by peat extraction in Latvia, to obtain information about these peatlands, and to prepare geospatial information and database. The tasks of geological and hydrological survey were to obtain information on the location of areas influenced by peat extraction, and their key characteristics (area, condition, peat properties, depth of residual peat layer).

Material and methods

Area identification, data collection and analysis

In order to identify and characterize areas affected by peat extraction, the following methods were used: cartographic analysis, analysis of the information from the Peat Fund (Latvijas valsts meliorācijas un projektēšanas institūts 1980), analysis of databases, literature and archives, as well as expert interviews. In result, 78 territories were selected for geological field inventory. More about site selection: see Chapter 4.5.

The key features of the areas selected for field inventories as as follows: partially or completely overgrown peat extraction milling fields or block-cut areas; functioning drainage system; a network of technological roads, railroads or other infrastructure elements established for peat extraction.

Field inventory

During the summer 2018, 78 selected sites (10,463 ha) were surveyed (Figure 57).

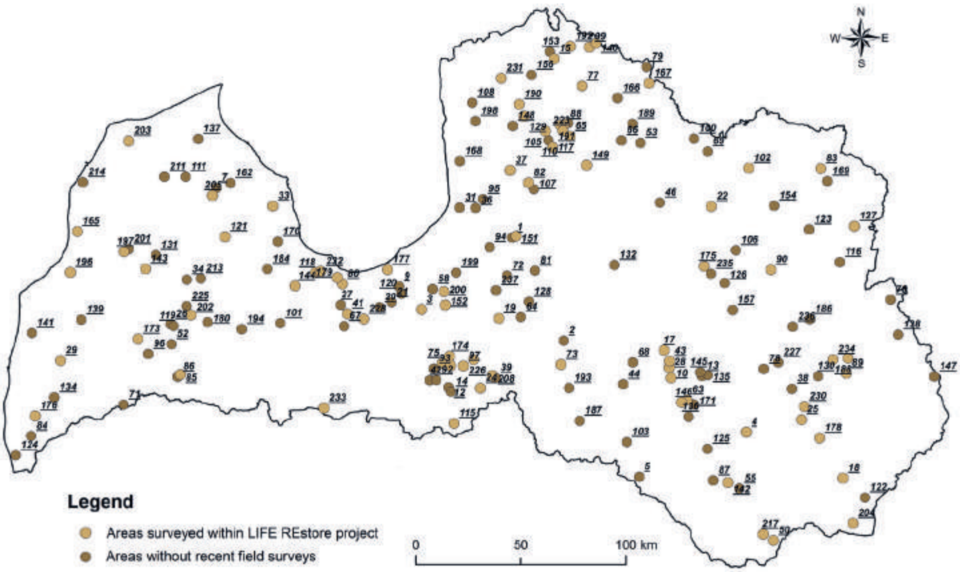

Figure 57. Surveyed peatlands. Names of sites according to the numbers used in this figure and inventory database are listed in Annex I. Author of map: A. Rudusāne.

The indications of peat extraction were assessed both in maps and in field. Activities related to peat extraction in the territory were recorded: peat milling fields, block-cut areas after manual cutting, block-cut areas after mechanized cutting, peat drying and stacking fields, remains of narrow-gauge railways and peat extraction machinery, or other evidence of peat extraction in the past. If no signs of peat extraction were found, further exploration of the site was not continued, and indications evidencing that the peatland was not used for peat extraction were recorded.

Prior to the study, information on the territory was gathered by exploring maps and earlier studies (LIFE REstore 2018). During field visits, special data form was filled out and photos were taken. Photos of the deposit samples were particularly important, given that peat cores can oxidize rapidly and their colour is changing.

The hydrological regime is very important in peatland development as it determines its formation, peat type and the character of its accumulation. Groundwater table can be influenced by geological and climatic conditions such as amount of precipitation, and human activity through the establishment or reconstruction of drainage system. Therefore, in addition to geological research, attention was also paid to peatland hydrology – surveying ditches, evaluating their condition, documenting their depth and depth of water, as well as the estimation of water flow. In areas with only internal ditch system, the depth and water level of the largest ditches was recorded. Initially, establishment of three boreholes was planned in each study site. However, there were areas with less boreholes due to various circumstances (for example, the area was flooded); in some cases, no boreholes were made. During the inventory, the following parameters were recorded:

- ✔ peat layer thickness was measured by coring; average thickness of the peat layer in the territory was calculated;
- ✔ the type of upper peat layer was determined by visual examination;
- ✔ degree of peat decomposition was determined for the upper peat layer, according to von Post scale (von Post, Granlund 1926);
- ✔ the pH value was measured using a portable pH meter;
- ✔ the type of mineral ground deposits was determined visually by obtaining a sample of mineral soil under the peat layer;
- ✔ for further studies and interpretation of data, 3–5 samples of upper peat layer were obtained at all sites, and at least one representative peat sample was obtained from peat layer below the upper layer. The peat core (about 0.5 m in length) of each upper deposit layer was sampled and packed for further studies, in case if needed for further interpretation of field observations. Information on peat extraction site and exact location (coordinates) was attached to each sample;
- ✔ depth of groundwater table was measured with a special tape, in boreholes and in ditches.

The results on condition of degraded peatlands, depth of peat layer, peat type, pH value and other information are informative. Inventory was not carried out in accordance with Cabinet Regulation No 570 Processes for the Extraction of Mineral Resources. In the future, prior to the selection and implementation of reclamation measures, substantial additional information may be necessary.

Results and discussion

Characteristics of an area affected by peat extraction, including its geological structure and characteristics of the residual peat layer are important for reasoned decision on the after-use. Peatlands affected by peat extraction are of various ages and with different origins and development history.

Raised bog peat dominates in the upper layer of 37 surveyed peatlands. Cutaway peatlands with fen peat in the upper layer are slightly less common; 29 such peatlands were found. Only in two cases peatlands with transitional mire peat were found. In seven sites, all peat layer was extracted reaching the mineral ground (LIFE REstore 2018).

Different depths of the residual peat layer were recorded. Generally, it varied from 0.5 to 1.5 metres. In some cases, the depth of peat varied significantly within a single peatland. For example, in Skuju Mire (No 197 in LIFE REstore project database, see location in Figure 57) it was 0.5 m in one borehole and 2.25 m in the second one. In Skrunda Mire (No 34) not only peat depth differed (from 0.5 m to 1.7 m) but also the type of deposits below the peat. In a small distance (about 50 m), it changed from fine-grained yellowish-grey sand without admixture of organic matter, to blue-grey clayey silt with roots of plants. This indicates on different conditions of peat accumulation, which should also be taken into account when planning reclamation. The relief of mineral ground usually is uneven, with depressions or elevations. Therefore, conclusions on peat depth and peat properties may be inaccurate if only one or few localities in mire have been studied.

Usually, fen is the first stage of mire development. Also in this study fen peat typically was located above the mineral deposits.

The thickness of its remained layer in various mires usually varied from 0.2 m to 1.2 metres. There were exceptions: 3.15 m thick fen peat layer in Taudejāņu Mire (No 233) and Zaikava Mire (No 235) – 4.9 metres. Of all the studied peatlands, in 29 sites the residual peat layer consisted of fen peat. In 12 peatlands, this layer was thicker than 1.9 m (Figure 58); this should be taken into account along with other peatland parameters in selection of after-use scenario or deciding of further peat extraction.

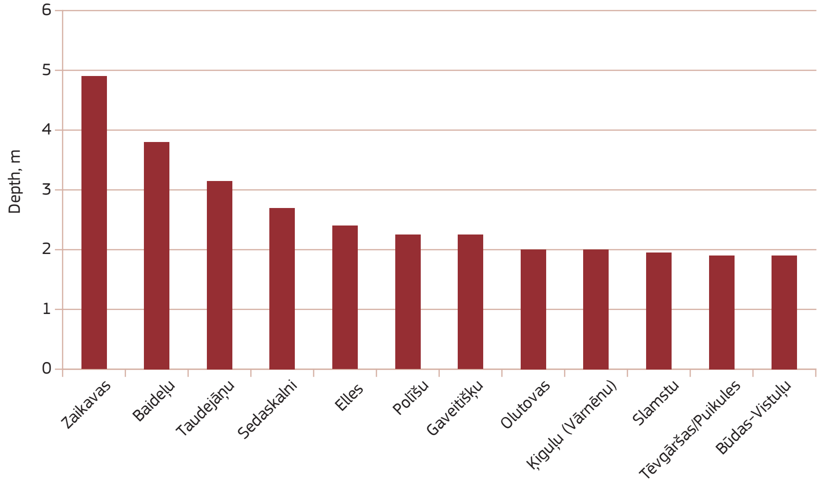

Figure 58. Peatlands with residual fen peat layer deeper than 1.9 m (LIFE REstore inventory data).

Most commonly, silt was found in the mire bottom (eight peatlands), including clayey and sandy silt. Clay deposits (clay, silt loam and clayey sand) were recorded in seven peatland areas. Only in four peatlands, sand deposits were found under the peat. In Elle Mire (No 178), moderately decomposed fen peat was accumulated on silt with mollusc shells (Figure 59). In Zemdegu Mire (No 225), well decomposed fen peat was accumulated on clayey silt (Figure 60). In Sedaskalna Mire (No 141), highly decomposed fen peat was located on silt clay (Figure 61).

Figure 59. Elles Mire: 2.4 m thick moderately decomposed fen peat on silt with mollusc shells.
Photo and data: K. Libauers.

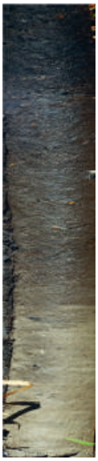

Figure 60. Zemdegu Mire: 1.3 m thick well decomposed layer of fen peat, accumulated on clayey silt.
Photo and data: O. Aleksāns.

Figure 61. Sedaskalna Mire: 2.7 m thick well decomposed layer of fen peat, accumulated on silty silt clay.
Photo and data: O. Aleksāns.

In the studied areas, fen-type peat usually was moderately well decomposed (degree of decomposition 20–30%) or well decomposed (> 30%). In few sites, peat decomposition degree was 40% or higher, making identification of peat type on field conditions nearly impossible, as it was hard to distinguish between peat and peaty sapropel.

In cutaway peatlands with residual fen peat and high groundwater table, vegetation consisted of fen plant species. Groundwater table usually was high (0.5 m below the ground). It was averagely high (0.5–1.0 m) in two areas and low (< 1.0 m below the ground) in four areas. In four peatlands, groundwater table varied within a single peatland, varying from average to high or low. In residual fen peat, the soil water pH value was influenced both by precipitation, surface water and groundwater, so the pH value varied between 3.51 and 6.99. In peatlands with peat of several types, pH varied from 3.92 to 6.86.

Only in two sites, transitional mire peat was found in the entire section, including the upper layer. In Būdas-Vistuļu Mire (No 107), residual peat layer is 1.9 m thick and it consists of moderately decomposed grass-Sphagnum peat accumulated on silty silt deposits. In Frišmaņu Mire (No 108), moderately decomposed (20–30%) 3.8 m thick grass peat is located on clayey silt (Figure 63). In some areas, transitional mire peat has been found below the raised bog peat, for example, in Slēperu Mire (No 199) where moderately decomposed (20–30%) 2.1 m thick transitional mire type grass peat is located below a 0.8 m thick Sphagnum peat layer, above grey, fine-grained sand. Groundwater tables in peatland ditches are 0.3–0.4 m below the ground surface; the average pH value of groundwater is 6.

Peat is most often extracted in raised bogs. Consequently, in most of surveyed peatlands, residual peat or its upper layer consists of raised bog peat with poor (5–20%), less commonly with moderate (20–30%) decomposition rate. The thickness of residual peat layer is variable regardless of its location in the relief. This may be also related to economic changes and changes of land ownership which resulted in cessation of peat extraction in a particular deposit.

The range of residual peat layer thickness in peatlands varied between 0.2 and 7 m. In 21 peatlands, it was greater than two metres. In the following areas the residual peat layer was the deepest: Ozolmuižas-Bambišķu Mire (No 213) – 4.9 m; Robežnieku-Purmaļu Mire (No 65) – 5.5 m, Zaķu Mire (No 233) – 5.5 m. In Ķoniņu Mire (No 152) it reached up to 7 m (Figure 62).

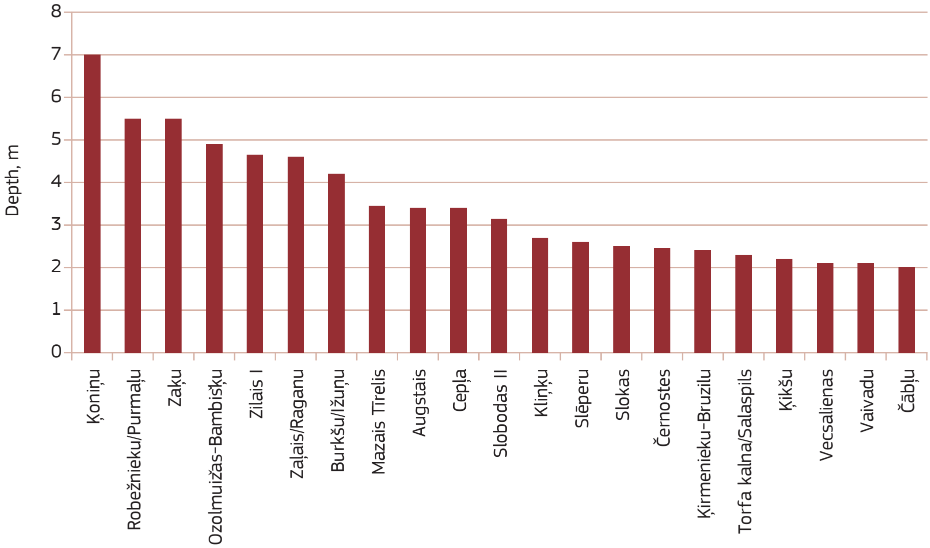

Figure 62. Peatlands with raised bog peat (depth greater than 2 m), data according to inventory of LIFE REstore.

In peatlands, where the residual raised bog peat layer is several metres thick, and it covers the transitional or fen peat, it is quite homogeneous throughout the section, both in terms of botanical composition and decomposition degree. For example, in Robežnieku-Purmaļu Mire, the whole section is composed of poorly decomposed (5–20%) *Sphagnum* raised bog peat (Figure 64), indicating on intensive peat accumulation under rather stable moisture conditions. A similar course of peat accumulation was observed in a section of Zaķu Mire (Figure 65). The deepest peat layer accumulated on mineral ground is usually well decomposed.

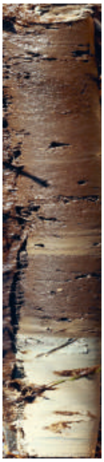

Figure 63. Frišmaņa Mire: 3.8 m thick moderately decomposed (20–30%) transitional mire peat on clayey silt deposits. Photo and data: O. Aleksāns.

Figure 64. Robežnieku-Purmaļu Mire: poorly decomposed (10–20%) raised bog Sphagnum peat. Photo and data: K. Libauers.

Figure 65. Zaķu Mire: moderately decomposed (25–30%) raised bog *Sphagnum*-cottongrass peat. Photo and data: P. Džeriņš.

In raised bogs, high groundwater table (not exceeding 0.3 m below the ground surface) dominates during the peat formation. In three cutaway peatlands with residual raised bog peat, low water table was observed (more than 1 m below ground) indicating on drainage impact. In four peatlands, groundwater table was moderate (0.5–1.0 m below the ground), and in five peatlands it ranged from high (< 0.5 m) to medium (0.5–1 m), or even low (> 1.0 m). This can be explained by uneven relief of the mineral ground and by different hydrological and hydrogeological conditions as raised bogs often develop on boundaries of watersheds (Overbeck 1975; Šnore 2013; Маслов 2008). When comparing water levels in ditches and boreholes, it was observed that in cutaway peatlands, where groundwater tables were similar in all boreholes, also the residual peat layer depth was similar. For example, in Vecsalienas Mire (No 193) the groundwater table varied between 0.4 m and 0.45 m, and the peat layer depth changed from 2.10 m to 2.25 metres. In the ditch, water was stagnant and there was no flow. However, the water level was varying (0.5–1.3 m), which can be explained by the fact that the ditch was partially overgrown. In Robežnieku–Purmaļu Mire, residual peat layer depth varied from 0.4 m to 6.0 m, and groundwater table in all boreholes was 0.2 m below the ground. Although the ditch was shallow (water level 0.1 m) and partially overgrown, minor flow of water was observed. One-off groundwater flow measurements of this inventory provided a general idea and information on the hydrological regime in surveyed peatlands. Information on parameters, such as type of residual peat layer and its depth, is important in selecting after-use scenarios. However, it should be noted that situation may also partially change after the reconstruction of drainage system.

Analysis of sediments in relief depressions with mires, in 16 raised bog type peatlands, it was found that these mires initially developed over sand with gravel admixture (in two sites) or on silty sand. Silty clay, clay, sandy till and clayey till were in the bottom of 13 raised bog type peatlands. These sediments are poorly permeable that created suitable conditions for mire development. The properties of these sediments are important for the selection of after-use scenarios for the particular peatland as they provide information on preconditions of mire formation – whether the mire is developed on mineral ground or by overgrowing of water body.

When planning reclamation of cutaway peatlands that have development after paludification of mineral ground, it must be taken into account that the territory will lack from constant groundwater supply. In such cases, suitable after-use scenarios may be afforestation and berry cultivation (taking into account the existing supply of groundwater table and precipitation). If the mire has developed after overgrowing of water body, sapropel accumulates in early stages of mire development. Approximately one third of Latvian mires have developed and are still developing by overgrowing of water bodies. However, only in seven surveyed peatlands sapropel was found below the peat (for example, Torfakalna Mire (No 201) and Govju Mire (No 227). This can be explained by the fact that mires developed after paludification of mineral ground are more often used for peat extraction (compared to mires developed after overgrowth of lakes) because they are characterised with thick layers of raised bog peat with rather homogeneous botanical composition and poor decomposition, e.g. Dzelve Mire (Kušķe et al. 2010). In addition, peat extraction was usually started in marginal areas of mires where peat layers are younger than in the central part. If mire development started with overgrowth of lake and later reached the stage of raised bog, there are no sapropel sediments below the peat in edges of such peatland (Markots et al. 1989; Kalniņa, Markots 2016).

All inventory results are available in database created during the LIFE REstore project, at https://restore.daba.gov.lv/public/lat/datu_baze1/ (see Chapter 4.5).

Conclusions

The results of the geological and hydrological inventory of peatlands provide the necessary background information on 78 studied peatlands, their geological structure and hydrological conditions. This information is essential to decide on the after-use scenarios of the particular areas. The geological structure of the studied peatlands is relatively simple. In most cases, the layers of different peat types and decomposition degrees do no intermingle in the residual layers. This indicates on stable conditions during peat accumulation, which may also have a favourable effect on the reclamation success. Problems can be caused by the relief of mineral ground. Therefore, additional geological surveys are necessary both before the applying reclamation measures or resuming of peat extraction.

In more than ten areas with residual fen peat (Klaškinu-Kājiņu, Lielstaldātu, Skuķu, Vējiņu Vizbuļu, Dzilnu Mires, etc.), residual peat layer depth is less than 0.6 metres. They have developed on sand sediments. Groundwater table is moderate or high. These peatlands are suitable for establishment of perennial grasslands, paludicultures (reeds *Phragmites australis*, cottontails *Typha* spp., reed canary grass *Phalaris arundinacea*). After adjusting the drainage system, they will be suitable for the establishment of agricultural land.

In surveyed peatlands with residual raised bog peat, thickness of peat layer varies from 0.3 m to 7 m, with a low (5–20%), or (less often) moderate (20–30%) degree of decomposition. Groundwater table is usually high. These properties and low pH value (≤ 5) indicate that these peatlands are suitable for recovery of peat-forming vegetation, for cultivation of *Sphagnum* and berries.

In most of the surveyed peatlands, peat layer has formed on mineral ground during paludification process. This indicates that creation of water bodies will not be successful in these territories – there is no evidence of plentiful groundwater supply, and the amount of water provided by precipitation will not be sufficient to fill up the water body. Only in seven sites of surveyed peatlands the creation of water bodies could be successful.

Of 78 peatlands surveyed, in 21 areas with residual raised bog peat and in 12 areas with residual fen peat the were thicker than 1.9 metres, indicating that these sites are suitable for mire rehabilitation and for cultivation of plant species which are not limited by thick peat layer.

However, in order to ensure rational use of peat resources, in areas where peat extraction is economically feasible and which are already severely influenced by peat extraction, the most appropriate management option would be continuation of peat extraction and then choosing the most appropriate after-use scenario for the particular site conditions.

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Annex I. List of peatlands (see Figure 57)

No according to inventory database*	Name of peatland	No according to inventory database*	Name of peatland
1	Airīšu/Senmāču	68	Kaķīšu
2	Aizkraukles (Aklais)	69	Kalna
3	Augstais	70	Kalnsalas/Beržovkas
4	Baideļu	71	Kalšu
5	Baltmuižas	72	Kardes/Ošiņu
7	Bērzu	73	Karkuļu
9	Bieriņu	75	Klaškinu/Kājiņu
10	Bikstu	77	Kliņķu
12	Bitenieku	78	Kņavu/Kņovu
13	Borovkas	79	Ķeizaru
14	Briģu	80	Ķemeru/Smārdes/Tīreļu
15	Brīvpurvs	81	Ķēviešu
17	Bukšu	82	Ķiguļu
18	Burkšu/Ižuņu	83	Ķikšu
19	Būdas-Vistuļu	84	Ķirbas-Tīreļa
20	Cenas	85	Ķirmenieku-Brizilu
21	Cenas tīrelis/Melnā ezera purvs	86	Ķirmenieku-Dadžu
22	Cepļa	87	Ķīrupes
24	Čābļu leja	88	Ķoniņu
25	Černostjes	89	Ladušu
26	Dižais Veiķenieku	90	Lagažu/Šņitku
27	Drabiņu	92	Lambārtes
28	Driksnas-Vilku	93	Lamzenes
29	Durbes	94	Laugas
31	Dzelves/Kroņa	95	Laugu/Laugas
33	Dzilnu	96	Lauķu
34	Eģenieku	97	Lādzēnu
36	Eipuru/Pēterupes	99	Lejas dambji
37	Elles	100	Lesiņu
38	Ezera/Ciskādu I	101	Lestenes/Ēnavas
39	Ērgļu	102	Lielais
41	Frišmaņa	103	Lielais Aknīstes
42	Galenieku/Lakstīgalas	105	Lielais II/Zažēnu/Mujānu
44	Gargrodes	106	Lielais Mārku/Ušuru
46	Gaujaslīču/Kaudzīšu	107	Lielais Unguru
50	Gaveitišķu	108	Lielais-Ērgļu
52	Gāgu	110	Lielais IV/Makuļu/Droņu
53	Geidas	111	Lielsalas
55	Gerlaku	112	Lielstaldātu
58	Getliņu	114	Līgotņu
63	Govju	115	Lunkiču
64	Grēperi/Kūdraiņi	116	Lutinānu
65	Jaunauču I	117	Maitiņu
66	Kačoru	118	Mazais Tīrelis
67	Kaigu	119	Mazais Veiķenieku

* The inventory database includes 237 areas affected by peat extraction that occur within 180 peatlands.

No according to inventory database*	Name of peatland	No according to inventory database*	Name of peatland
120	Medema	175	Skuķu
121	Mežkauliņu/Kalēju	176	Slamstu
122	Mšarina/Maišeļu	177	Slēperu
123	Naudiševas/Naudaskalna	178	Slobodas II
124	Nidas	179	Slokas
125	Nīcgales	180	Spundiņu
126	Olgas	184	Strēļu-Ēgeru
127	Olutovas	186	Stružānu
128	Ozolēnu	187	Sūnekļa
129	Ozolmuižas	188	Taudejāņu
130	Ozolmuižas/Bambišku	189	Taures
131	Ozolu	190	Tēvgāršas/Puikules
132	Palšu	191	Tilcēnu
134	Palta (Tīreļa)	192	Tīlikas/Tecēnu
135	Pertsalas/Kvītaines	193	Tīrais
136	Pētermuižas	194	Tīreļa
137	Piltenes	196	Tīrlauks
138	Plaudīšu/Degļovas	197	Tīrmales
139	Pleces	198	Toļļu
140	Pliča/Pirtes	199	Torfa II
141	Ploču	200	Torfa kalna/Salaspils
142	Pokšānu	201	Umuļu
143	Polīšu	202	Upatnieku
144	Praviņu	203	Uzkules (Branda)
145	Prisessolas	204	Vaivadu
146	Raganu	205	Valgales/Mačiņu
147	RAU (Kūdras fabrika)	208	Valles
148	Rāķa/Dzelves	211	Vasenieku
149	Rekšņu	213	Vānes/Stulbais Kalves
151	Rinkas	214	Vārves (Buļļu, Pūņu)
152	Robežnieku/Purmaļu	217	Vecsalienas
153	Rūjas	223	Vējiņu
154	Salenieku	225	Vilīšu
156	Sapatas	226	Vilku tīrelis
157	Saukas	227	Viļānu
162	Sārāju/Pūņu	228	Vizbuļu/Valgundes
165	Sārnates	230	Zaikavas
166	Sedas	231	Zaķu
167	Sedaskalna	232	Zaļais/Raganu
168	Seķu	233	Zemdegu
169	Siguldas/Silguldas	234	Zilais I
170	Sīļu	235	Zosu
171	Skrebeļu-Skrūzmaņu	236	Žagatu-Skušnovas
173	Skrundas	237	Žļaugu
174	Skuju		

* Inventarizācijas datu bāzē apkopotas 237 kūdras ietekmētās teritorijas, kas atrodas 180 kūdrājos.

4.3. Three-dimensional hydrogeological modelling in Lauga Mire and Ķemeri Mire demo sites

Oļģerts Aleksāns, Juris Pētersons

Summary

Within LIFE REstore project it was planned to restore two peatlands damaged by peat extraction and drainage: degraded raised bog in Lauga Mire Nature Reserve neighbouring with peat extraction area, and former peat extraction field in Ķemeri Mire (Ķemeri National Park). Restoration included rewetting by blocking of ditches in Lauga Mire, and adjusting the water table and reintroduction of Sphagnum mosses in Ķemeri Mire.

To evaluate the hydrological and hydrogeological conditions in both experimental restoration areas (demo sites) and their surroundings, as well as to find the most suitable solutions for rewetting, three-dimensional modelling of water flows was carried out. Modelling results were used in preparing reclamation design and technical design.

Introduction

During LIFE REstore project it was planned to restore two peatlands which were degraded by peat extraction and drainage. Mitigation of drainage impact was necessary in the raised bog in Lauga Mire Nature Reserve in order to prevent increased decomposition of peat surface, peat compaction, and vegetation degradation, which in turn leads to significant greenhouse gas emissions. Reintroduction of *Sphagnum* mosses was planned Ķemeri Mire (Ķemeri National Park), in part of the peatland damaged by peat extraction. Here, mire vegetation was unable to recover for decades, due to both too low water table and also well-pronounced water table fluctuations.

Hydrogeological and hydrological studies were aimed at elimination of problems found in both areas and at evaluation of peatland ecosystem recovery possibilities. This chapter summarizes the experience of LIFE REstore in three-dimensional hydrogeological modelling of the two project demo sites and their surroundings. The results of this study were subsequently used for the planning of rewetting in the project areas, as well as for the development of reclamation design and technical design (see Chapters 6.3.3 and 6.3.4).

Material and methods

Study areas

Hydrological and hydrogeological investigation and three-dimensional modelling were carried out in Lauga Mire and Ķemeri Mire (Figure 66), the demo sites where peatland restoration was planned within the LIFE REstore project (see Chapters 6.3.3 and 6.3.4).

One of the study areas is located in Lauga Mire Nature Reserve and in extracted peat fields adjacent to its south-eastern margin. Here, large cranberries are cultivated in part of the area, while some part of it is still used for peat extraction. Lauga Mire Nature Reserve was designated in 1999 for the conservation of threatened bird species and raised bog habitats. The nature reserve covers 740 ha and includes the central part of the Lauga Mire. There are two bog lakes in the nature reserve – Lake Višezers and Lake Lode (Freimane (ed.) 2017). Part of the bog is drained as it borders with the peat extraction fields, and the ditches are maintained in good condition. The ditches cause increased runoff, thus adversely affecting more than 300 ha of the raised bog and worsening its condition and deteriorating the ecosystem functions.

Ķemeri Mire, with a total area of over 6 000 ha, is a part of the Ķemeri National Park (designated in 1997). The research and modelling was carried out at the north-eastern margin of Ķemeri Mire, in the former peat extraction area near the complex of Krāču Hills Dune bordering with the motorway P101

Kalnciems–Kūdra. The total area affected by peat extraction covers about 180 hectares. Peat was harvested until 1980s (Ķuze, Priede 2008) creating a degraded area with partly extracted peatlands. Most of the extracted peatland is successfully recovering after raising the water table in 2006. The demo site selected by LIFE REstore covers several hectares of bare, dry peat fields where the rewetting in 2006 had not achieved the expected result. In 2016, when the planning of Sphagnum reintroduction started, in this part of the area the peat-forming vegetation and peat formation process had not recovered due to low and highly fluctuating water table.

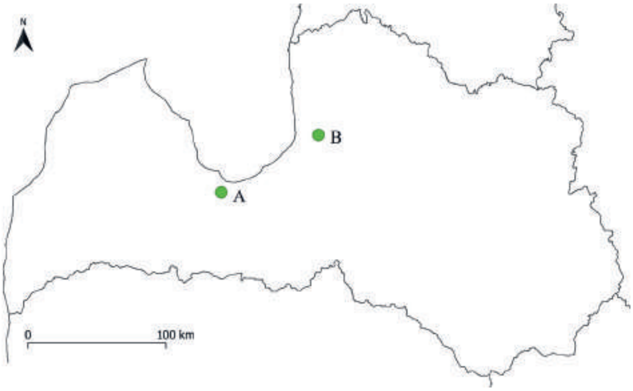


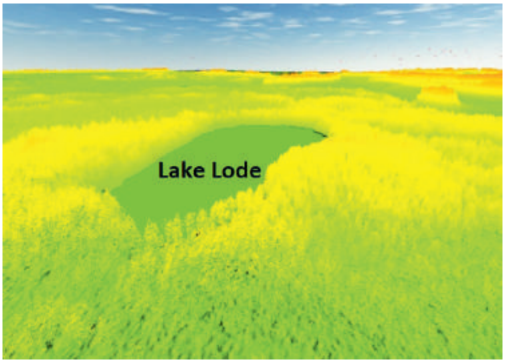
Figure 66. Location of modelling areas (LIFE REstore demo sites).
Author of map: A. Priede.

Three-dimensional modelling

The three-dimensional models of the project sites were developed using the geospatial data set provided by Nature Conservation Agency. The data set was used in accordance with Cabinet Regulation No 673 of August 30, 2011, "Mandatory Content of the Provisions for the Use of a Geospatial Data Set and Procedures for the Receipt of a Permit for the Use" and in accordance with the conditions of issued licence (transferred to Association "Baltic Coasts" for hydrological and hydrogeological research for LIFE REstore project). The digital relief model is provided for modelling the surface and groundwater flow; analysis of slopes; gradient analysis of water courses and drainage ditches; identification of watercourse catchment basins; analysis of mire surface morphometric parameters. The digital relief model is also being used for hydrogeological modelling of groundwater.

In order to create the digital relief model, laser scanning (LiDAR) data were used, which allow to obtain a three-dimensional data set of the surface, where X, Y and Z coordinates are assigned to each point with a precision of 5–20 cm (Figure 67). For data processing, a licensed program *Global Mapper* and its specific data processing module LiDAR were used.

A



B

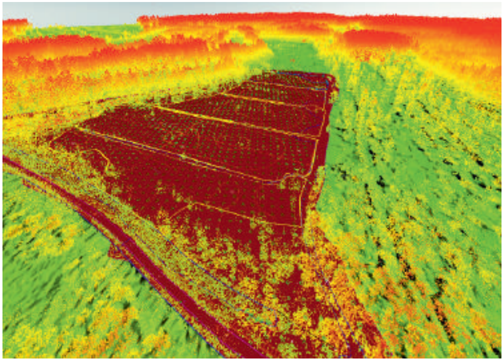


Figure 67. Examples of LiDAR three-dimensional data sets. A – part of Lauga Mire; B – part of Ķemeri Mire.
Author of maps: O. Aleksāns.

Hydrogeological modelling

Hydrogeological modelling was carried out in the Environmental Modelling Centre of Faculty of Computer Science and Information Technology, Riga Technical University. The model was used to determine the distribution of groundwater table, to identify groundwater flows and elements of their balance, and to assess the impact of drainage ditches on the overall status of groundwater in the demo sites and their surroundings. The study was conducted using *Groundwater Vistas 6* (Environmental Simulations 2004) software. For the graphic design, *Surfer 12* (Golden Software 2011) software was used. Data of Latvian hydrogeological model LAMO4 developed by Environmental Modelling Centre (Spalviņš 2015) were used.

The hydrogeological model consists of eight layers (Table 15, Table 16). The first and eighth layers are serving as boundary conditions with a fixed water level. The assumed thickness of these layers in the model is only 0.02 m, and they do not describe the real geological layers in field. However, they are needed as virtual elements in the model to define its boundary conditions. Also, the formal aquitard No. 2 is only necessary for the correct ascription of drainage ditches to the relief.

The third, fourth and fifth layers in the model represent, respectively, the upper B3, the middle B2 and the lower B1 parts of the peatland. The thickness and hydraulic conductivity *k* of these parts were chosen based on the results of B. Maslow (Маслов 2008) and L. Kalniņa (see Chapter N). The thickness of the upper part B3 is 0.7 m, *k* = 0.1 m/d. The thickness of parts B2 and B1 is the same, but their hydraulic conductivities are *k* = 0.01 m/d and k = 0.001 m/d, respectively.

Table 15. Vertical scheme of Lauga Mire hydrological model, and hydrogeological parameters used in this model.

No. of HM layer	Aquifer	Layer name	Layer code in model	Hydraulic conductivity (m/day)	Layer thickness (m)	Notes
1.		Topography	rel.	10.0	0.02	Boundary condition
2.		Top of aeration zone	aer.	0.1	0.02	
3.		Peatland top and till	B3, gQ	0,5 and 0.0014	0.7	k_z/k_{xy} = 0.1
4.		Peatland centre and till	B2, gQ	0.01 and 0.0014	0.5–10.2	Aquitard
5.		Peatland base and till	B1, gQ	0.001 and 0.0014	0.5–10.2	Aquitard
6.		Till	gQ	0.0014	14.0–23.7	k_z/k_{xy} = 0.3
7.		Salaspils aquitard	D3gj1z	0.00028	0.1–16.6	Aquitard
8.		Gauja aquitard	D3*gj*1	10.0	0.02	Boundary condition

Table 16. Vertical scheme of Ķemeri Mire hydrological model, and hydrogeological parameters used in this model.

No. of HM layer	Aquifer	Layer name	Layer code in model	Hydraulic conductivity (m/day)	Layer thickness (m)	Notes
1.		Topography	rel	10.0	0.02	Boundary condition
2.		Top of aeration zone	aer2	10^{-6}–1	0.02	
3.		Aeration zone and peatland surface	aer1, B2	10^{-4}–0.1	0.5–21.8	Aquitard
4.		Peat sediments	B1	10^{-4}	0.02–6.43	
5.		Quaternary sand	Q2	3.0	4.0–8.4	Aquifer
6.		Salaspils aquifer	D3slp2	10.0	0.5–8.2	
7.		Salaspils aquitard	D3slp1	0.00015	2.0	Aquitard
8.		Pļaviņu aquifer	D3pl	10.0	0.02	Boundary condition

Modelling of water table in Lauga Mire

The approximation step of the hydrogeological model grid is 4 metres. Digital terrain model adapted to the model requirements was used as an upper boundary condition (Figure 67a). Line of peatland edge separates peatland from sandy loam (black line in Figure 67a), for which, as for the Latvian hydrogeological model LAMO4, hydraulic conductivity has been defined as k = 0.0014 m/d.

Quaternary till sediments gQ are modelled in Layer 6, the lower surface of which is taken from LAMO4; k = 0.0014m/d was assumed as a till sediment hydraulic conductivity (Маслов 2008). As an upper gQ surface HM, an elevation 53 m above the sea level was used in the distribution range of peat sediments; it ensures the variation of peat deposit in the model (Figure 67b). In the south-western corner of the model, the height of the surface decreases due to relief depression.

Aquitard G3gj1z is modelled in Layer 7. Its thickness varies from a few metres in north-north-west part to 15 m and more in the south-eastern corner of the model. The assumed hydraulic conductivity for Gauja aquitard is k = 0.00028 m/d, using LAMO4 data (Spalviņš 2015).

A digital relief and HM geometric surface were used as a boundary condition in Layer 1. Here, digital relief was smoothened by digital filtering. Boundary condition for Layer 8 aquifer D3gj1 was taken from LAMO4 (Spalviņš 2015). The active part of the model consists of aquitard and therefore the surface of vertical sides of the model are waterproof, and water level boundary conditions are not used for them (except for Layer 1 and Layer 8).

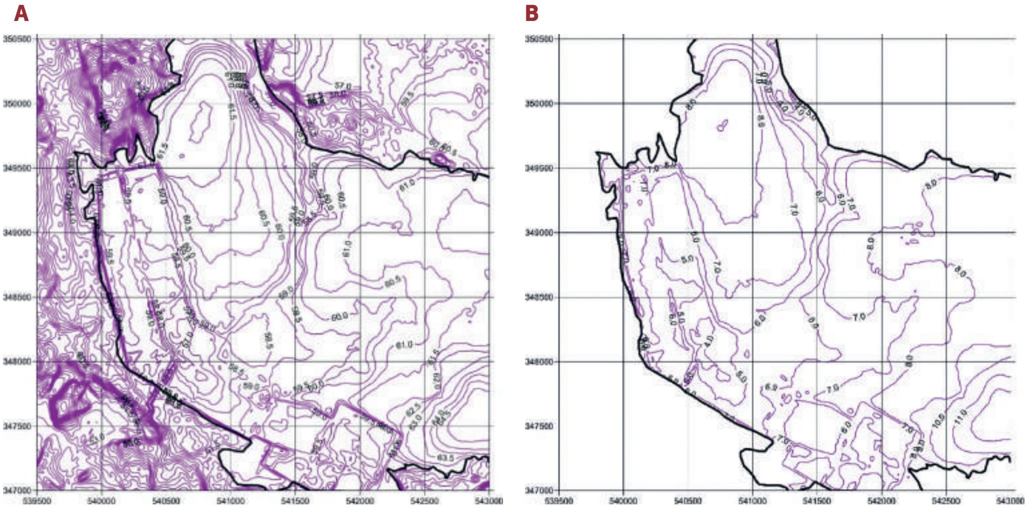


Figure 68. Lauga Mire: A – map of contour lines covering the project area; B – map of peat depth. Author of maps: O. Aleksāns.

For modelled water tables at mire bottom B1 and till gQ – see Figures 69a and 69b.

Components of the hydrographic network are "connected" to Layer 3 of B3. Ķīšupe river, the brook and the ditch are modelled as boundary condition *River* in *Groundwater Vistas* software, and the lake – as boundary condition *General Head Boundary* in *Groundwater Vistas.* Graphs of river, brook and ditch *groundwater* drainage discharge are generated by the *Groundwater Vistas* tool *Mass Balance*, in mode BC *Flow Accretion Curve*.

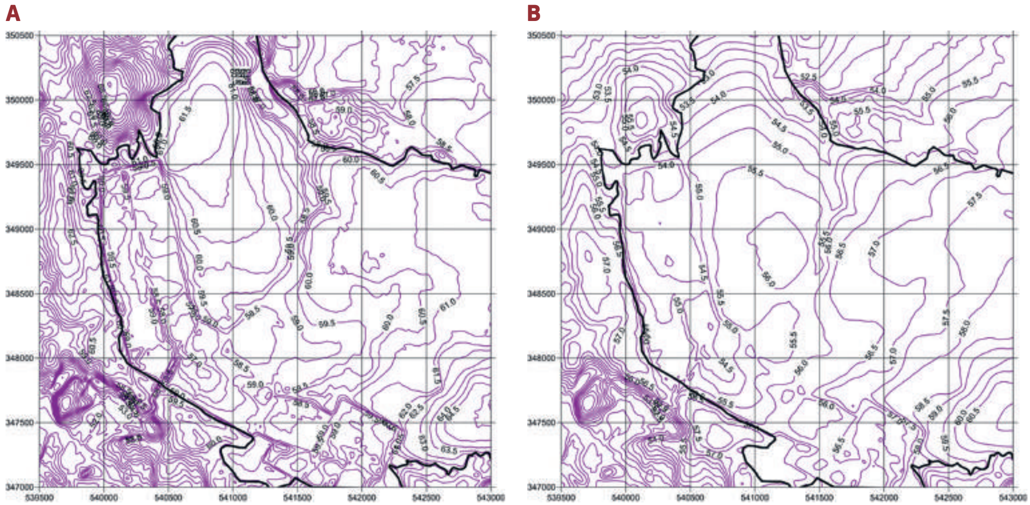


Figure 69. Modelled water tables at mire bottom B1 and in till gQ (Lauga Mire): A – groundwater table in Layer B1 (metres above the sea level); B – groundwater table in Layer gQ (metres above the sea level). Author of maps: O. Aleksāns.

Results and discussion

Application of three-dimensional models in the planning of peatland restoration

One of the most important parameters for the hydrological and hydrotechnical calculations of surface water objects (watercourses and water bodies) is the size and borders of the catchment areas. In peatlands with relatively flat relief, it is usually problematic and sometimes even impossible to identify a watershed between two adjacent catchment areas using the traditional methods (topographic contour lines). This problem is completely solved by the use of LiDAR data and the use of relevant software, which allows detailed and accurate morphometric analysis of the catchment areas even for very gently sloping peatland areas.

Using the digital surface models of project demo sites generated using LiDAR data, the catchment areas of Lake Višezers Lake (Lauga Mire) and part of Ķemeri Mire were obtained (Figure 70). Their boundaries (yellow line in the figure) were determined on the basis of the surface runoff model (blue lines in the map). Using this model, also the catchment areas of Lake Višezers and part of Ķemeri Mire were accurately determined (319 ha and 116.2 ha, respectively).

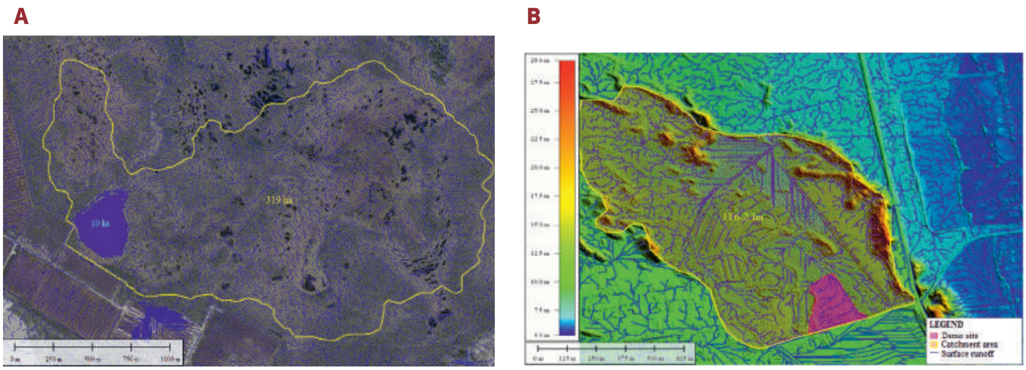


Figure 70. Catchment areas in the study areas, determined with three-dimensional model:
A – catchment area of Lake Višezers in Lauga Mire; B – catchment area in part of Ķemeri Mire. Author of maps: O. Aleksāns.

The advantage of spatial models is the possibility to define geometric parameters of surface water objects (width, length, depth of stream bed, longitudinal profile, etc.), which are very important data for hydrological and hydraulic calculations. This method also identifies various obstacles (such as dams) in watercourses and drainage systems. LiDAR data and digital surface model have been used for analysis of mire surface relief morphometric parameters and for modelling of water table rise.

Modelling of water table in Lauga Mire study area

According to the modelling results, about 180 m^3/day of groundwater is flowing from mire into the Viršupe river (called Ķīšupe river in lower reach). In the river section outside the mire where it flows through sandy clay sediments, there is no groundwater supply in the river does or it is insignificant and thus can be ignored. About 13 m^3/day of water flows from the upper, highly permeable peat layer into the stream which flows into Lake Višezers Lake in its eastern shore.

A relatively large amount of water (317 m^3/day) flows from the intact part of the mire into the collection ditch which borders with the peatlands in west-south-western direction. The results of the hydrogeological modelling show that about 70 m^3/day of water from Lake Višezers infiltrates into the deeper aquifers through its base. A small proportion of the water from the lake flows out as groundwater through its shore area. Hydrogeological modelling shows that the existence and hydrological regime of Lake Višezers is mainly ensured by water incoming from the upper, highly permeable layer of the mire consisting of poorly decomposed peat (acrotelm), as well as from surface runoff.

Using the option provided in the modelling program to determine the vertical groundwater flow rate V_z (m/day), it is possible to calculate the distribution of infiltration flows which is $V_z \times 365000$ (mm/year) for all layers of the model. This provides important information both on the water exchange among individual aquifers, and in the particular case – between mire sediment Layers B3, B2 and B1 which are virtually defined in the model.

The results of the modelling show that the most intensive infiltration occurs in the upper (B3) layer (Table 17). The supplementation of modelled groundwater aquifer (B3) from atmospheric precipitation in a result of vertical filtration (mm/year) in the project area and adjacent areas can be seen in Figure 71.

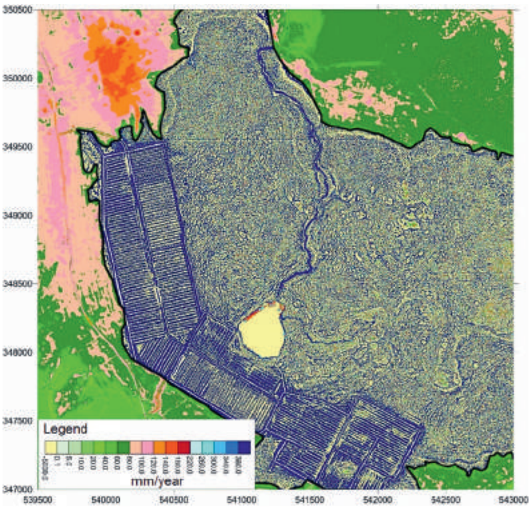


Figure 71. Supplementation of simulated mire sediment Layer B3 with atmospheric precipitation in a result of vertical infiltration (mm/year). Author of map: O. Aleksāns.

Intensive infiltration from atmospheric precipitation occurs in the whole complex of Lauga Mire, and it exceeds 300–350 mm/year. It is almost half of the average annual rainfall (763 mm). The amount of precipitation was calculated using 55-year period (1961–2016) data of two meteorological observation stations ("Sigulda" and "Skulte") which both are located ca. 18 km from Lauga Mire. For comparison, in the area adjacent to the mire, infiltration rates of atmospheric precipitation for the modelled B3 Layer are many times smaller and usually do not exceed 100–150 mm/year (Figure 71).

Simultaneously with precipitation infiltration, evapotranspiration occurs in the intact part of the mire, including evapotranspiration from the surface of Lake Višezers (yellow colour in Figure 71), which is not typical for a territory adjacent to mire. The mosaic pattern of the map indicates on the evapotranspiration from the upper Layer B3 (Figure 71).

Figure 72 shows the supplementation (mm/year) of mire water as a result of vertical filtration from the upper layer – for the modelled sediment Layer B2 (Figure 72a) and for the sediment layer B1 (Figure 72b). These charts show that the volume of vertical water recharge decreases with depth, which is also logical, because with increasing depth, the density of peat increases and its hydraulic conductivity decreases.

In the intact part of Lauga Mire, on average only 40–60 mm of water annually reaches the Layer B2 (Figure 72a). Towards the mire periphery, especially in the north-northwest direction (less intense in the south-eastern direction), the infiltration in Layer B2 increases to 80–100 mm per year. These are the sections where the lower peat Layer B1 receives water mainly by infiltration from the upper sediment Layer B2. This means that there is a more intense vertical water recharge from the top down if compared to the mire central part.

A summary of groundwater balance component calculation for the entire area of Lauga Mire, obtained with *Mass Balance* (built-in tool of the modelling program), is shown in Table 17.

Table 17. Calculation of groundwater balance components for Lauga Mire model territory.

Layer code	Water amount, m^3/day									
	Upper part of the layer			Lower part of the layer			Total	Through the model boundaries	In rivers and ditches	In lakes
	Inflow	Outflow	2 + 3	Inflow	Outflow	5 + 6	4 + 7			
1	2	3	4	5	6	7	8	9	10	11
Aeration zone	12688	-10067	2621	9973	-12594	-2621	0	0	0	0
B3	12594	-9973	2165	782	-2963	-2181	441	0	-510	70
B2	2963	-782	2181	4	-2184	-2180	0	0	0	0
B1	2184	-4	2180	0	-2180	-2180	0	0	0	0
gQ	2180	0	2180	1	0	-2179	1	-1	0	0
D3gj1	2179	0	2179	0	-2179	-2179	0	0	0	0
Model	12688	-10067	2621	0	-2179	-2179	442	-1	-510	70

Table 17 shows that intensive inlet (12,688 m3/day) and outlet (-10,067 m3/day) of water occurs in acrotelm (defined as aeration zone in the model). It is important to note that water recharge through the base layers of the model (column 7 in Table 17) is almost the same at all levels – about 2180 m3/day. This amount of water eventually reaches the upper Devonian Gauja aquifer and supplements its groundwater supply. However, the horizontal flow (column 8 in Table 17) does not occur in all aquifers except the upper Layer B3.

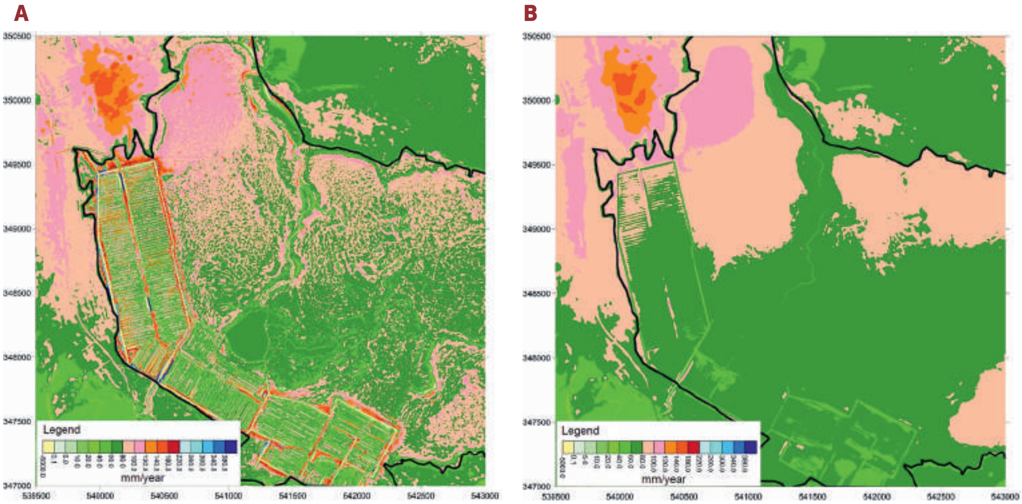


Figure 72. Supplementation of modelled water supply as a result of vertical filtration from upper layer (mm/year):
A – peat sediment Layer B2; B – peat sediment Layer B1. Author of maps: O. Aleksāns.

Modelling of water table in Ķemeri Mire study area

The approximation step of the hydrogeological model grid is 10 metres. As an upper boundary condition, the model uses a digital relief model adapted to model requirements (Figure 73).

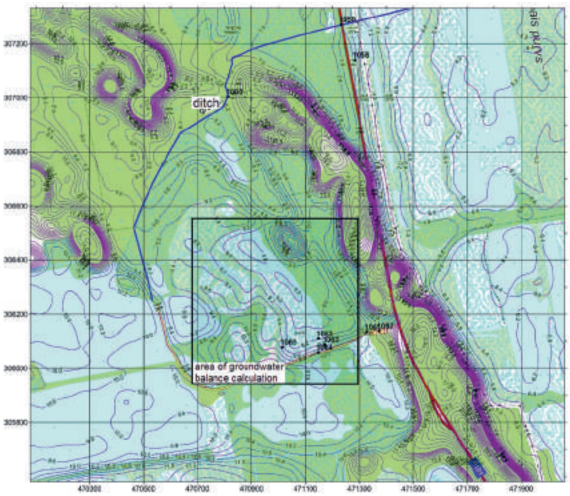


Figure 73. Relief map with contour lines of Ķemeri Mire modelling area. Author of map: O. Aleksāns.

The modelled groundwater table in the sand Layer Q2 is shown in Figure 74. The water tables in aquifers Q2 and D_3slp2 in Ķemeri Mire modelling area are very close, as these aquifers are hydraulically closely related and therefore their tables are not separated. It has been also confirmed by groundwater table maps prepared in previous studies (Prols 2010).

For the boundary condition aquifer D_3pl, the layout of contour lines is homogeneous, with a gradient of about 0.0012. However, the water table field in Quaternary sandy sediments (Q2) aquifer is very uneven due to the influence of nearby Krāču Hills sand dune. To the west and east from the sand dune, gradients of flows are 0.00043 and 0.0017, respectively. The shape of contour lines changes due to the influence of drainage ditch in the vicinity of sand dune.

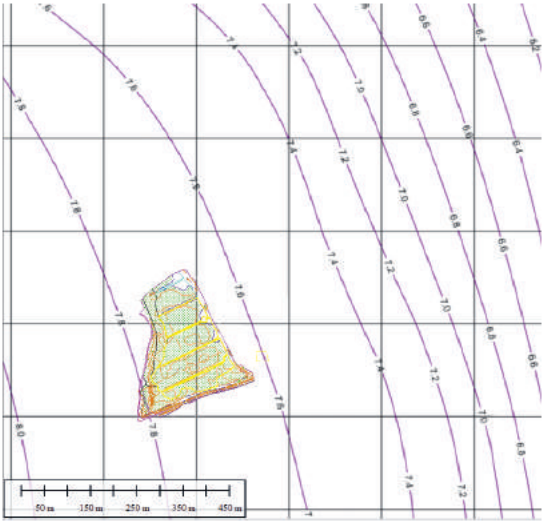


Figure 74. Modelled groundwater tables in aquifer Q2 (metres above the sea level) in Ķemeri Mire modelling area. Author of map: O. Aleksāns.

In the model, the ditch draining the mire is connected to Layer 3 (B2) but in the area of sandy sediments – to Layer 5 (Q2). The ditch is modelled as the boundary condition *River* in the *Groundwater Vistas* software. Modelling results show that water discharging into the ditch from peat sediments constitutes only about 10% of the total amount of water that enter this ditch. The ditch receives water mainly from Quaternary sandy sediment aquifer, which accounts for about 90% of its total water balance.

Important information is obtained by modelling the vertical flows and water exchange between the aquifers. Model results show that the most intensive infiltration occurs in the Quaternary sandy sediment Layer (Q2), especially in the zone close to the sand dune adjacent to the eastern boundary of Ķemeri Mire study area. Figure 75 shows a map of the modelled unconfined aquifer (Q2) water supply supplementation as a result of vertical filtration (mm/year) in the project area and adjacent areas.

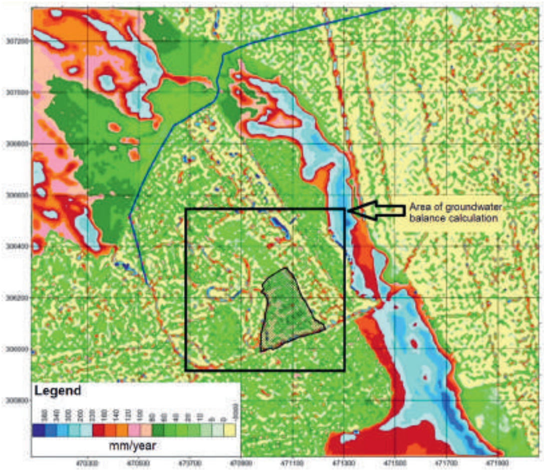


Figure 75. Map of water supplementation resulting from vertical filtration (mm/year) in the modelled unconfined aquifer (Q2) in Ķemeri Mire study area. Author of map: O. Aleksāns.

With the exception of dune area and north-western part of the model area, the supplementation of groundwater in the unconfined aquifer Q2 is rather balanced – the amount of water inlet is approximately similar to that of the outlet, as evidenced by the mosaic pattern of infiltration map in Figure 75. In the eastern-north-eastern part of the model area, the upward water flow is slightly dominating (yellow tones). In the central and south-western part, downward filtration trend is dominating (green tones). The figure shows configuration of ditches, which means that they are hydraulically connected with the unconfined aquifer.

Groundwater balance component calculation area including research area in Ķemeri Mire is summarised in Table 18; but for the entire model area – in Table 19.

The most important information about the Ķemeri Mire research area is given in Table 18 as it describes the local situation more precisely (the outlined area in Figure 75). In the demo site, the upward water flow in the upper, well-conducting (acrotelm) Layer (B2), is relatively intensive (-29.5 m^3/day). It is about half of the amount of water that enters here as precipitation. Almost all of the remaining amount of precipitation water (-31.1 m^3/day) that enters peat, is infiltrated in the unconfined aquifer (Q2) below the peat. The horizontal flow in the peat layer is negligible – only 0.5 m^3/day.

About 31.1 m^3 of water per day enters the sandy sediment layer (Q2) from the upper horizon. About 26.4 m^3/day of this water recharges to lower horizon, but the rest of the water enters into the ditches as a horizontal stream. There is actually no downward flow.

In the aquifer D$_3$slp2 in Ķemeri Mire demo site, water exchange occurs in approximately similar amounts both in horizontal and vertical directions. However, there is no water accumulation or deficit in the aquifer because the balance of water that inflows and outflows the aquifer is approximately the same.

The total amount of water circulating in confined aquifers in Ķemeri Mire study area is very small, and its influence on the hydrological situation in the area is negligible. Modelling results show that, for this reason, for the restoration of mire, additional surface water supply from adjacent areas will be necessary.

Calculation of subsurface water balance components for the entire Ķemeri Mire model area is given in Table 19. Compared to the small demo site, the situation is similar in the wider surrounding area, though slightly different in some groundwater balance components.

Similarly as in Ķemeri Mire study area, also in the entire model area most of water (192.7 m^3/day or less than 30% of the amount which enters the first model aquifer (B2) in the form of precipitation which is 666.7 m^3/day) flows away through the well-filtering acrotelm and ditches, or is lost through evapotranspiration. This means that most of precipitation does not contribute in the total groundwater balance. A small amount of water (~4.2 m^3/day) from the model layer B2 enters the drainage system and is discharged through ditches or filtrates through the ditch bottom into the unconfined aquifer Q2 (-479.6 m^3/day) via horizontal flow (mainly in areas without peat sediments).

Unlike the upper layer B2, the component of horizontal groundwater is significantly higher in aquifer (Q2) composed of sandy sediments. However, its absolute value is negative (-82.1 m^3/day). This means that this layer in the groundwater balance acts as the main groundwater discharge area with inlet into the surface hydrological network, thus supplementing the surface watercourses and water bodies. Large part of the water (-385.0 m^3/day) from this layer (Q2) enters the underlying aquifer D3slp2.

In the aquifer D3slp2, water exchange, similarly as in the project area, is approximately equal in both horizontal and vertical directions. Its inlet through the layer top is 385.0 m^3/day, outlet through the layer bottom – 175.1 m^3/day, and horizontal runoff – 180.4 m^3/day. The model does not indicate that this aquifer under the project area would have any hydraulic connection to surface water.

Table 18. Calculation of groundwater balance components in Ķemeri Mire demo site.

Layer code	Water amount, m^3/day												
	Layer top			Layer bottom			Total	Layer boundaries*					Ditch
	inflow	outflow	2 + 3	inflow	outflow	5 + 6	4+7	R	A	Z	D	9 + 10 + 11 + 12	
1	2	3	4	5	6	7	8	9	10	11	12	13	14
B2	60.1	-29.5	30.6	0.0	-31.1	-31.1	-0.5	0.1	0.2	0.0	0.2	0.5	~15–20**
Q2	31.1	0.0	31.1	0.0	-26.4	-26.4	4.7	8.7	-10.5	-5.1	2.2	-4.7	~3–4**
D3slp2	26.4	0.0	26.4	0.0	-23.6	-23.6	2.8	26.5	-24.2	-12.1	7.0	-2.8	0.0
Model	60.1	-29.5	30.6	0.0	-23.6	-23.6	7.0	35.3	-34.5	-17.2	9.4	-7.0	

Table 19. Calculation of groundwater balance components for the entire Ķemeri Mire model territory.

Layer code	Water amount, m³/day												
	Layer top			Layer bottom			Total	Layer boundaries*					Ditch
	inflow	outflow	2 + 3	inflow	outflow	5 + 6	4+7	R	A	Z	D	9 + 10 + 11 + 12	
1	2	3	4	5	6	7	8	9	10	11	12	13	14
B2	666.7	-192.7	474.0	9.2	-479.6	-470.4	3.6	0.1	0.0	0.0	0.5	0.6	-4.2***
Q2	479.6	-9.2	470.4	29.5	-385.0	-355.5	114.9	11.4	-53.5	-41.0	1.0	-82.1	-32.8
D3slp2	385.0	-29.5	355.5	0.0	-175.1	-175.1	180.4	40.9	-137.5	-87.1	3.3	-180.4	0.0
Model	666.7	-192.7	474.0	0.0	-175.1	-175.1	294.9	52.4	-191.0	-128.1	4.8	-261.9	-37.0

** W, E, N, S – west, east, north, south boundary of the balance calculation area.*
*** Estimated approximately, as the difference between the sums of groundwater balance components.*
**** Only horizontal flow (without surface water).*

Application of modelling results in demo sites

Preparation of three-dimensional hydrological models and determination of water flow directions and amounts in Lauga Mire and Ķemeri Mire was an important step towards the implementation of LIFE REstore project activities. The modelling results were used in planning rehabilitation of the former peat extraction area and rewetting of drained raised bog, for preparation of reclamation design in Ķemeri Mire demo site (see Chapter 6.3.3), and technical design for Lauga Mire (see Chapter 6.3.4).

The hydrological model of Lauga Mire allowed to identify the boundary of Lake Višezers catchment area, which, according to research results, covers most of the raised bog. Modelling results allowed to assess the importance of Lake Višezers in functioning of Lauga Mire, as well as to determine the directions and velocities of water exchange. It was found that the Lauga Mire is a place where groundwater is being supplemented, although the water flow is very slow. Using the obtained data, it was possible to develop innovative technical solutions for rewetting of Lauga Mire (see Chapter 6.3.4) and to present and justify this approach in negotiations with land owners of adjacent territories, as well as with Limbaži Municipality Building Board, Regional Environmental Board, and other authorities.

Modelling in the Ķemeri Mire demo site allowed to understand the complexity of this territory. It was found that in area where *Sphagnum* reintroduction was planned, the modification of hydrological regime was necessary in order to make the site suitable for *Sphagnum* mosses and other raised bog plant species. Modification of hydrological conditions is aimed at adjusting the water table so that is suitable for peat-forming vegetation. Water table should not be too low (0.2–0.5 m below the peat surface), and not too high, covering the peat surface. In order to prepare the area for *Sphagnum* reintroduction, the surface preparation was necessary to diminish the surface gradient and to ensure inflow of water. It was also necessary to make sure that the hydrological conditions in the adjacent territories as far as possible were stable and similar to those in the demo site.

When developing the hydrogeological models in LIFE REstore demo sites in Lauga Mire and Ķemeri Mire, also the most suitable locations for water table monitoring were identified. After modelling, monitoring wells were established, and groundwater table was monitored during the project.

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4.4. Spontaneous revegetation in cutaway peatlands in Latvia

Māra Pakalne, Agnese Priede, Laura Grīnberga

Summary

In the LIFE REstore project, vegetation was surveyed in 32 extracted peatlands in the period from 2016 to 2018. The surveyed peatlands included both former block-cut and vacuum harvested areas. Typical vegetation types occurring in the former peat extraction areas were identified, and influence of drainage, water table and other factors was evaluated. The results of LIFE REstore inventory were supplemented with data from similar studies carried out in Latvia. In total, results from 39 cutaway peatland areas in Latvia have been included in this study.

Several scenarios of spontaneous revegetation were identified. They were distinguished by dominant properties of residual peat layer, peat extraction methods, and moisture conditions. Each scenario includes several succession stages. Overall, the results describe the process of spontaneous revegetation in various conditions in Latvia, although not all variations could be included in this overview. The main factors determining the course of spontaneous revegetation in cutaway peatlands are groundwater table, type and properties of residual peat, its physical and chemical properties, as well as hydro-chemical parameters of water bodies. The restoration of peat-forming mire vegetation and hence the peat accumulation process is possible only in wet conditions, which is important when planning rehabilitation for mire ecosystem and its functions, including carbon sequestration, regulation of water and nutrient cycling, and soil formation.

The results of this inventory were used to identify the factors which should be taken into account in planning rehabilitation of peatlands damaged by peat extraction, i.e. restoration of peat-forming vegetation. Abandonment of such degraded peatlands leading to natural succession cannot be considered rehabilitation in cases when the impact of drainage system is not eliminated.

Introduction

Peatland ecosystems have diverse functions, and they play a significant regulatory role in nature (Joosten, Clarke 2002; Joosten 2003; Rydin, Jeglum 2006). Peatlands, which include various types of mires, forests, grasslands and other types of ecosystems on organic soils, contribute to regulation of global climate and micro-climate, ensure water and nutrient cycling, and function as natural pollution filters (Smith et al. 2013). They also have an important aesthetic and recreational role and they are an important source of various materials (peat, water, biomass, medical and food plants, etc.). Peatland ecosystems are critically important for biodiversity conservation. Most of species in mires are highly specialised to certain ecological conditions, as many of them occur only in particular mire types. The remains of these organisms (pollen, spores, macro-remains) stored in peat, provide unique information on the past development of peatland and surrounding areas, thus being valuable nature "archives".

In spite of important peatland functions and their crucial role in nature, they have been destroyed and modified for centuries – drained, transformed into agricultural areas and forests, used for peat extraction. As a result, many peatlands, also in Latvia, have been completely destroyed and transformed into other land use types.

There is a strong relation among vegetation, water and peat in mires. Changing any of these components leads to modification of others. Lowering of groundwater table causes vegetation changes, and the process of peat accumulation can be interrupted. Then, this can lead to increased peat decomposition causing significant greenhouse gas emissions.

Peat extraction includes establishment of drainage systems, significant lowering of groundwater table and surface preparation. This is a dramatic change in the ecosystem resulting in altered hydrological regime, removal of vegetation and soil. Natural ecosystem functions are interrupted, and peatland is transformed into an artificially maintained environment which is regulated by a drainage system. As a result, peatlands turn from carbon sinks into sources of greenhouse gas emissions (Joosten, Couwenberg 2009).

Development of peat-forming vegetation and recovery of mire ecosystem functions are possible if appropriate moisture conditions are re-created after peat extraction (Nishimura, Tsuyuzaki 2014). Recovery success of mire ecosystem and its natural functions (water storage, carbon sequestration, etc.) depends on the after-use scenario in the former peat extraction sites and rehabilitation measures applied.

This chapter provides an overview of vegetation types occurring in areas affected by peat extraction, as well as success of vegetation recovery resulting both from rehabilitation measures and natural succession in abandoned cutaway peatlands in Latvia. Various scenarios of vegetation succession in different site conditions with diverse history and main influencing factors are presented. Since the course of vegetation recovery depends on the site conditions, the knowledge of these tendencies may be used in planning of rehabilitation measures.

Material and methods

During the LIFE REstore project, in 2016–2018 vegetation was surveyed in 32 extracted peatlands. The results of this survey were supplemented with data obtained in two other projects: PuReST (2014/0009/1DP/1.1.1.2.0/13/APIA/VIAA/044; 2014–2015) and National Conservation and Management Programme for Natura 2000 Sites in Latvia (NAT-PROGRAMME, LIFE11 NAT/LV/000371; 2012–2017). In total, 39 sites were investigated (Figure 76). All surveyed sites have been used for peat extraction, but reclamation measures, except for rewetting and sphagnum reintroduction in very few areas, have been not carried out or they have failed. In all of the surveyed territories, peat extraction was completed or discontinued. The survey also includes water bodies created after cessation of peat extraction.

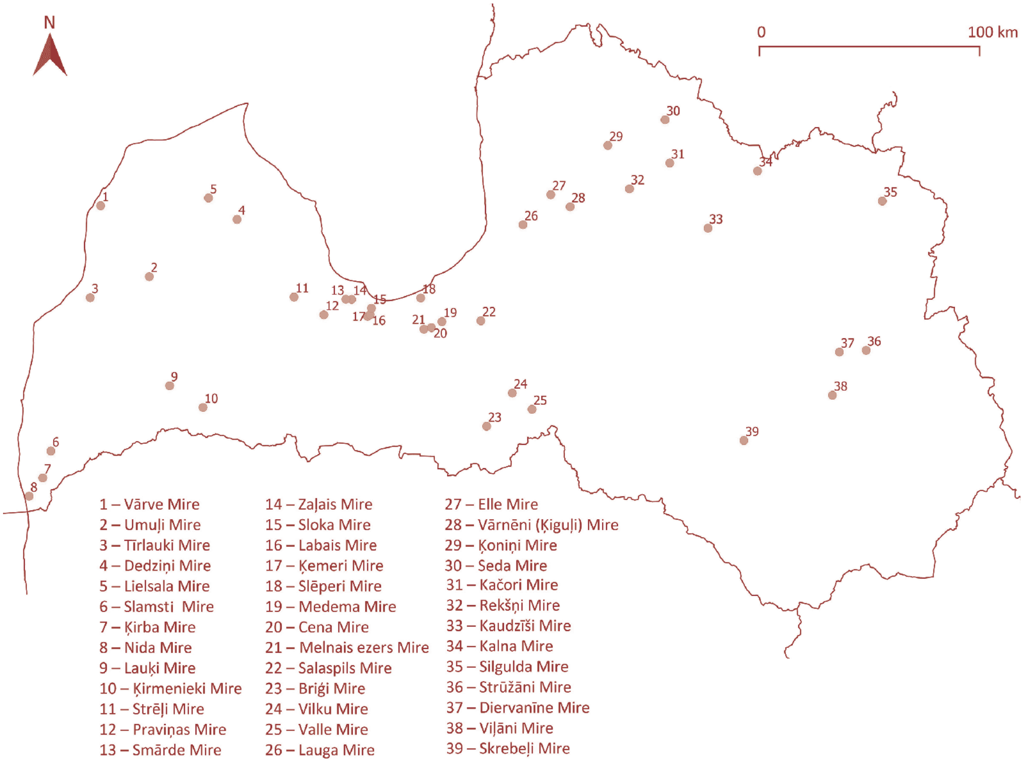

Figure 76. Locations of the areas surveyed.

The surveyed sites included both block-cut areas (peat quarries and block-cut peat fields) and milled (vacuum harvested) peat fields. In rather many cases more than one harvesting method had been used in a single peatland, thus the areas were not always homogeneous. The history of every single peatland was not known, i.e. cessation of harvesting. Peat extraction had been interrupted at various times – in the oldest peat cutting areas ca. 60–70 years ago, in some cases the areas were abandoned recently. The surveyed sites represented different depths of residual peat, different peat types and properties, as well as various moisture conditions and vegetation succession stages.

First of all, the locations of survey sites were identified using orthophotomaps and topographic maps; after determining their locations the survey routes were planned. Dry peat fields which were easily accessible were surveyed by walking across the area diagonally. Areas where walking was heavily burdened or impossible (water bodies, block-cut areas with flooded trenches) were surveyed from the available parts to record vegetation and other parameters.

Prior to peatland inventory, a special field data form was developed. In total, 127 field data forms were filled (available in the project database[27]). Field data forms include information on peatland type, degradation degree, vegetation composition and structure, drainage systems and their influence (expert opinion); other important conditions which were visually assessed (such as residual peat type, peat decomposition, erosion, etc.). Hydrological conditions were assessed in each site. Taxa of vascular plants, bryophytes and lichens were identified and their abundance estimated. Invasive and protected species were accounted separately. Vascular plants were named according to Gavrilova and Šulcs (1999); bryophytes and lichens – according to Āboliņa et al. (2015). All areas were photographed.

27 Degradēto purvu atbildīga apsaimniekošana un ilgtspējīga izmantošana Latvijā, https://restore.daba.gov.lv/public/lat/datu_baze1/ (only in Latvian).

Information on the time since peat extraction was gathered from various sources (local governments, landowners, peat producers, local inhabitants, maps from different time periods). There was no information on reclamation measures applied, except for very few areas with published information or information available from the peat extraction enterprise, landowner or other sources. Vegetation types and succession stages were distinguished on basis of similarities in site conditions and vegetation composition. Results and conclusions were complemented with knowledge from similar studies, as well as experience of authors of this chapter.

Results and discussion

General course of spontaneous revegetation of cutaway peatlands in Latvia

Inventory results show the vegetation structure and species composition, as well as spontaneous revegetation under different hydrological conditions with various peat types and properties (such as pH, peat type, decomposition). After peat extraction, depending on the conditions in the particular site, vegetation characteristic to degraded peatlands or secondary peat-forming mire vegetation and water bodies can develop. In highly degraded drained peatlands, the succession leads to development of forest vegetation, whereas in rewetted areas peat-forming mire vegetation may be found. In inundated areas, aquatic vegetation develops with species composition and structure determined by the depth and depth variations of the particular water body and its hydrochemical parameters.

While evaluating the vegetation in a particular site, the time period since cessation of peat extraction must be always taken into account. Fairly often, different conditions (e.g. residual peat type, moisture) can be found in a single peatland, and various parts of a peatland has been extracted and abandoned at different times. As a result, vegetation differs by species composition and structure, as it is related with the succession stage. For example, in many peatlands, peat extraction is being continued in some parts, while the abandoned sections overgrow with forest, peat-forming mire vegetation, reedbed or aquatic vegetation.

Block-cut areas and quarries were usually abandoned in the mid-20th century, and nowadays have mostly overgrown with peat-forming mire vegetation. Meanwhile, other parts of the same peat deposit may have been extracted later using vacuum harvesting (milling) method or peat is still being extracted or recently abandoned. This results in various vegetation succession stages in different sections of a single peatland.

After the completion or discontinuation of peat extraction, there are many common characteristics for degraded peatlands abandoned without rehabilitation (or in some of them the rehabilitation has not been successful). The average water table is lower than optimal for mire vegetation development. In addition, cutaway peatlands suffer from large seasonal water table fluctuations (Triisberg et al. 2011). Our inventory did not include water table monitoring; however, the influence of low and highly fluctuating water table is well reflected in the vegetation (Waddington et al. 2001; Poschlod et al. 2007). In summers, the peat surface may be very dry and it heats up; large areas are exposed to wind erosion. In winters, peat erosion is caused by frost heave. Such conditions are ongoing for decades after peat extraction cessation, making the restoration of mire characteristic vegetation impossible.

Figure 77. Development of peat-forming vegetation in wet peat fields in Melnais ezers Mire. Photo: M. Pakalne.

During the surveys, also peatlands with successful development of peat-forming mire vegetation were identified (Figure 77) which was possible mainly due to high water table which can result from intentional rewetting, or can be caused by clogging of ditches, sometimes the ditches have been blocked by beavers.

Numerous studies abroad (Lavoie et al. 2003; Konvalinková et al. 2011; Gonzàlez et al. 2014) as well as LIFE REstore inventory and some other studies in Latvia suggest that reintroduction of peat-forming vegetation and consequent accumulation of peat is possible only in sites where mean annual water table reaches the ground surface or is slightly lower, but not lower than averagely ca. 0.3 m below the peat surface. Results of LIFE REstore project and studies elsewhere in Europe (e.g. Smolders et al. 2003) show that development of mire vegetation is possible also in shallowly inundated (up to 0.3 m above the ground surface) peatlands. Bog vegetation, including *Sphagnum* blankets, develops only in wet, acidic conditions without large water table fluctuations. Mire vegetation can survive in such conditions for a few dry years. However, if such conditions prevail for a long time, the area is not suitable for peat-forming vegetation. Low water table is the most important limiting factor for mire vegetation development (Poschlod 2007; Gagnon et al. 2018; Zając et al. 2018). Peat type and properties, including pH, are substantially influencing vegetation composition and the expected results in the long term (Poschlod et al. 2007; Priede et al. 2016).

The composition of vegetation largely depends on the residual peat type (fen, bog, transitional mire peat), its properties and depth. If the residual peat layer is thin, the physical and chemical properties of soil water may be predominantly determined by groundwater influence. Water storage capacity is also affected by residual peat depth and water permeability in the bottom of peatland. In case if the permeability of mineral deposits is high and the peat layer is thin, the conditions might be unfavourable for peat-forming vegetation.

Brown mosses and few *Sphagnum* species establish themselves in depressions with slightly acidic or alkaline residual fen or transition mire peat. The herbaceous vegetation is dominated by sedges and rushes. If drainage system is still functioning, wetland plants cannot establish, thus species-poor vegetation of dry or mesic places develops – ruderal pioneer vegetation at an early stage and vegetation of dry to mesic grasslands at later succession stages. After several decades, such drained peatlands overgrow by forest.

In cutaway peatlands with residual bog or transition mire peat, acidic environment and high water table, *Eriophorum vaginatum* (Figure 78) is the most common pioneer species, sometimes also *E. polystachion.* In later stages, *Sphagnum* species, *Oxycoccus palustris*, *Drosera rotundifolia* and some other bog plants establish themselves. Within several decades, along with increasing species richness, micro-relief similar to that in intact raised bogs (hummocks and depressions) may develop.

Figure 78. *Eriophorum vaginatum*, a characteristic, often dominant plant species in both dry and wet cutaway peat fields. Photo: M. Pakalne.

Dwarf shrubs, a characteristic component of raised bog vegetation, can be found both in dry and wet peatlands. However, their proportion depends on moisture conditions. In dry peat fields, *Calluna vulgaris*, less frequently other dwarf shrub species, may be the dominant species. In wet conditions, the dwarf shrubs occur only on dry elevations; in later succession stages – on hummocks.

In cutaway peatlands with dry acidic bog peat, especially in early succession stages, the species diversity is very low. Dry degraded peatlands are dominated by

Eriophorum vaginatum, *Calluna vulgaris* (less frequently, other dwarf shrubs), *Betula* spp., *Pinus sylvestris*. Few bryophyte species of dry coniferous forests may be present (e.g. *Pleurozium schreberi*, *Dicranum polystachion*), whereas *Sphagnum* species cannot establish due to too dry conditions. Thus, the peat accumulation process and consequently also mire ecosystem functions do not recover. In the long run, such dry peatlands, if not restored, overgrow with forest vegetation typical for severely drained peatlands.

Dry cutaway peat fields are suitable for spreading of invasive moss species *Campylopus introflexus*. Though not yet found in other habitats in Latvia, currently it is present in nearly all abandoned vacuum harvested peat fields that serve as a stepping stone for its further spread in dunes, heaths and other natural and semi-natural dry habitats, becoming a major threat to biodiversity (Mikulášková et al. 2012; Priede, Mežaka 2016).

Revegetation scenarios after cessation of peat extraction

After cessation of peat extraction, various vegetation types can develop. High water table is the most important prerequisite for development of mire vegetation and peat formation. In dry peat fields, there are very few mire species with wide ecological amplitude, such as *Eriophorum vaginatum* and *Calluna vulgaris*, as observed also in similar studies in Latvia (Ķuze, Priede 2008; Priede 2013) and elsewhere (Lavoie et al. 2003; Orru et al. 2016). However, if peat is wet for most of the year and even shortly flooded in case of high rainfall, conditions are suitable for development of peat-forming vegetation.

In wet conditions, development of mire vegetation is determined by several factors, e.g. peat type (fen, transitional mire or bog peat), peat properties (pH, mineralization rate and chemical composition of mire water), residual peat thickness, degree of decomposition (Lavoie et al. 2003; Nishimura, Tsuyuzaki 2014). In a single area, the environment can be heterogeneous due to natural conditions, amount of time since cessation of extraction and methods of peat extraction. Consequently, a mosaic of vegetation with different vegetation types may develop (Figure 79). The bottom of peatland is usually uneven, thus the mire vegetation may intermingle with mineral "islands", which in longer period of time overgrow with forest.

Figure 79. Mosaic of various conditions and vegetation development stages in part of Cena Mire around Melnais ezers Mire. Map prepared by A. Priede using the orthophotomap of 2003–2008, scale 1:10,000, © Latvian Geospatial Information Agency.

During LIFE REstore project and other studies in Latvia (e.g. Priede 2015; Priede et al. 2016), several post-harvesting scenarios of spontaneous revegetation were identified, as described below. Each scenario includes several stages of vegetation development (succession) at various conditions grouped after the residual peat type and peat extraction method.

Cutaway peatlands with residual raised bog peat

Cutaway peatlands with residual raised bog peat is the most common type of degraded peatlands affected by peat extraction in Latvia. Vacuum harvested peat fields cover the largest areas, whereas block-cut areas and peat quarries cover smaller areas.

Several vegetation types may develop in cutaway peatlands with residual poorly decomposed acidic bog peat (pH ~2.8–4.5) (Figure 80).

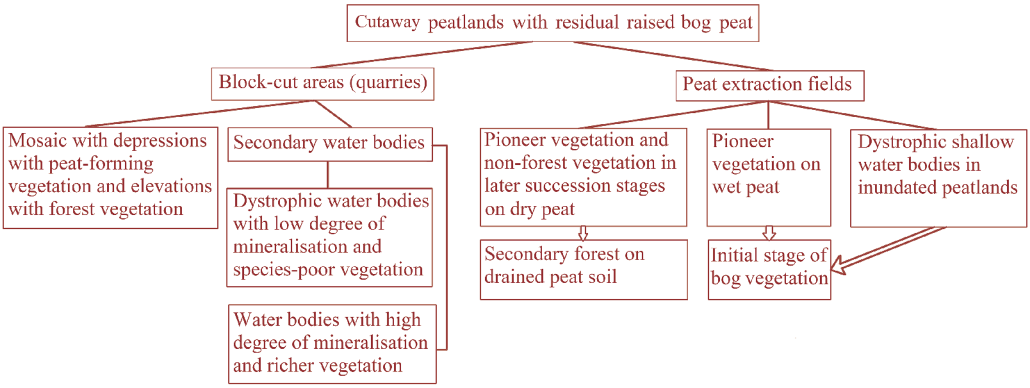

Figure 80. Spontaneous revegetation of cutaway peatlands with residual raised bog peat. Arrows indicate the directions of vegetation development.

Mosaic of secondary mire and forest vegetation in block-cut peatlands

Vegetation structure and composition. Vegetation is heterogeneous, as determined by uneven relief developed during peat extraction (Figure 81). The relief is composed of narrow, linear, deep depressions (trenches) separated by steep, narrow elevations, and wide linear pits separated by dry elevated strips. In Latvia, the block-cutting method was widely used until the 1950s–1960s (Šnore 2013).

In deep trenches, open water can remain for decades, while shallower depressions have overgrown with *Sphagnum* carpet accompanied by herbaceous species, such as *Eriophorum vaginatum*, *E. polystachion*, *Rhynchospora alba*, *Juncus* spp., *Phragmites australis*, *Carex canescens*, *Calla palustris*, *Menyanthes trifoliata*, etc. A few decades after cessation of peat extraction, the vegetation may be similar to lakeshore quaking bogs and raised bog depressions.

The elevated strips remain dry, thus they are overgrown with *Pinus sylvestris* and *Betula* spp. Ground vegetation is dominated by dwarf shrubs (typically *Calluna vulgaris*, often also *Vaccinium vitis-idaea*, *Vaccinium uliginosum*, *Empetrum nigrum*, *Ledum palustre*), dry forest bryophytes (*Pleurozium schreberi*, *Dicranum* spp.), lichens (*Cladonia* spp., *Cladina* spp.), often clubmosses (*Lycopodium annotinum**[28], *L. clavatum**) are present.

28 Hereinafter asterisk (*) means species which are protected in Latvia (included in Cabinet Regulation No 396 of 14 November 2000, On the list of Specially Protected Species and Specially Protected Species Whose Use is Limited).

Figure 81. Old block-cut area in Ķemeri Mire. Photo: A. Priede.

Occurrence. Fairly often (e.g. Ķemeri Mire, Sloka Mire, Labais Mire, Medema Mire, Viļāni Mire, Briģi Mire, Slēperi Mire, Salaspils Mire). The micro-relief of elevations and depressions created by peat extraction can be found also in the periphery of some relatively undisturbed raised bogs in Latvia (e.g. Zemgaļi Mire, Buļļi Mire, Palši Mire).

Major influencing factors. Drainage influence in peatlands extracted by block-cutting is less distinct than in vacuum harvested areas and have a rather local impact (Priede (ed.) 2017). After cessation of peat cutting, the trenches have filled up with water and are usually overgrown with mire vegetation. Spontaneous revegetation in shallow quarries is more successful. In deeper excavated ponds, overgrowing occurs mainly along the banks, and recovery of mire vegetation might take longer time.

In larger water bodies, overgrown areas are relatively small, mainly unfavourably affected by waving. The vegetation composition in water bodies of block-cut areas is primarily determined by physical and chemical properties of water (Klavins et al. 2011; Purmalis 2014).

Secondary water bodies in abandoned block-cut areas

Vegetation structure and composition. The vegetation cover of large, relatively deep water bodies is sparse (Figure 82), mainly dominated by *Phragmites australis*. Along the shores with shallow water, the vegetation is most often composed of *Carex rostrata*, *Juncus effusus*, *J. conglomeratu*s. Very rarely (only in water bodies with influence of calcareous groundwater), *Cladium mariscus** can be found. Submerged vegetation is nearly absent (most commonly *Utricularia* spp., while *Chara* spp. occur in hard-water bodies with well-pronounced influence of calcium-rich groundwater). The banks usually are steep, with exposed peat that may be covered with lichens *Cladina* spp. and *Cladonia* spp. On gently sloping banks, peat-forming *Phragmites-Sphagnum* vegetation may develop.

Figure 82. Rather deep excavated pond with small vegetation cover in the former block-cutting area in Sloka Mire. Photo: A. Priede.

Occurrence. Rarely (e.g. Ķemeri Mire, Slamste Mire, Zaļais Mire, Sloka Mire, Smārde Mire).

Major influencing factors. The main vegetation influencing factors are the hydro-chemical parameters (the basic properties are well indicated by electric conductivity and pH). Water depth and area size are also important, as deeper, larger ponds experience greater wave impact, hindering development of floating vegetation. The character of vegetation is also determined by succession stage, though peat cutting in this type of areas in Latvia was completed around the middle of the 20th century.

Dry peat fields with residual raised bog peat

Vegetation of early succession stage

Vegetation structure and composition. Shortly after peat extraction, there are usually only a few plant species (often the only species is *Eriophorum vaginatum*). Later, the species richness slightly increases. Vegetation is dominated by *Eriophorum vaginatum*, *Calluna vulgaris*, *Polytrichum commune*, *P. juniperum*, *Cladonia* spp., *Cladina* spp., *Bryum* spp., *Betula pubescens*, *Pinus sylvestris*; occasionally, carpets are formed by *Polytrichum commune*. The vegetation remains sparse, species-poor for a long time, dominated by hummocks of *Eriophorum vaginatum* and clusters of *Calluna vulgaris* that intermingle with bare peat (Figure 83). Invasive moss species *Campylopus introflexus* is often present.

Figure 83. Species-poor vegetation with Eriophorum vaginatum on dry peat field in Lielsala Mire. Photo: A. Priede.

Occurrence. Often (e.g. Lauga Mire, Tīrlauku Mire, Vārnēnu Mire, Rekšņu Mire, Slēperu Mire, Cena Mire).

Major influencing factors. Dry conditions are caused by functioning drainage systems. It is likely that vegetation development is influenced by properties of the upper peat layer which, due to drainage, is highly decomposed, with poor water storage capacity. The upper layer of peat heats up in summer and is affected by frost erosion in winter that hinders development of mire vegetation (Quinty, Rochefort 2000). Due to extreme growth conditions, there are few viable seeds (Salonen 1987; Price 1996). The surfaces are relatively flat, so the conditions are usually rather homogeneous. Wet depressions where mire vegetation may develop are rare (most likely, in sites of former bog hollows). An important factor affecting the species richness is the proximity of donor sites – relatively undisturbed mire with similar conditions (Quinty, Rochefort 2003).

Succession. This type of vegetation represents early succession stage which, due to extreme growth conditions, may last for several decades. The shorter the time since peat extraction, the poorer the vegetation, the more homogeneous its structure. The dominant species *Eriophorum vaginatum* can be characterized as a tolerant species under various conditions, able to grow in acidic bog peat both in wet and dry conditions (Poschlod 2007). However, the hummocks of *Eriophorum vaginatum* and its dead litter serve as a “shelter” for newly arrived plants in the extreme conditions. Within few decades, the co-dominating role is taken over by *Calluna vulgaris* and other dwarf shrubs, as well as bryophytes of dry coniferous forests, such as *Pleurozium schreberi* and *Dicranum polysetum* along with the lichen pioneer species (*Cladonia* spp., *Cladina* spp.).

Within 30–40 years such drained cutaway peatlands overgrow with forest dominated by *Pinus sylvestris* and *Betula* spp. The proportion of *Eriophorum vaginatum* and dwarf shrubs in the ground vegetation decreases, whereas the cover of bryophytes increases.

Secondary forests

Vegetation structure and composition. Typical species are *Eriophorum vaginatum*, *Calluna vulgaris*, *Vaccinium uliginosum*, *V. vitis-idaea*, *Ledum palustre*, *Empetrum nigrum*, *Lycopodium annotinum**, *L. clavatum**, *Pleurozium schreberi*, *Dicranum* spp, *Cladonia* spp., *Cladina* spp.. The tree layer is dominated by *Pinus sylvestris* and *Betula* spp. In young woodlands with sparse vegetation, the invasive moss species *Campylopus introflexus* is often found. In general, vegetation is very similar to that of elevations in block-cut areas.

Occurrence. Often (e.g. Cena Mire, Medema Mire, Vārve Mire, Silgulda Mire, Nida Mire, Vārnēni Mire, Rekšņi Mire).

Major influencing factors. The development and composition of forest vegetation is mainly influenced by functioning drainage system.

Succession. Establishment of trees begins soon after cessation of peat extraction, though most of seedlings do not survive in extreme conditions (drought, heating up, wind erosion, frost heave). More or less closed canopy in dry peatlands usually starts to develop within a few decades after peat extraction. It is likely that the establishment of trees in late succession stage is sheltered by herbaceous vegetation. As vegetation with typical forest structure and conditions develops, the proportion of herbaceous plants and dwarf shrubs decreases, while the cover of bryophytes-increases.

Wet peat fields with residual bog peat

Vegetation of early succession stage

Vegetation structure and composition. The most common species are *Eriophorum vaginatum*, *E. polystachion, Sphagnum cuspidatum*, *Drosera rotundifolia*, *Rhynchospora alba*, *Trichophorum alpinum*, *Dicranella* spp. Vegetation is relatively homogeneous and consists mainly of *Eriophorum vaginatum*. In areas with high water table, the open shallow water or wet peat among hummocks of *E. vaginatum* is being gradually occupied by *Sphagnum* species (Figure 84, 85), most commonly *Sphagnum cuspidatum*, the dominant species at pioneer stage.

Figure 84. Pioneer vegetation with cotton grass hummocks in an inundated peatland. Photo: M. Pakalne.

Figure 85. Establishment of Sphagnum blanket in a wet peat field with shallow water. Photo: M. Pakalne.

Occurrence. Rather rarely (e.g. Melnais ezers Mire, Lielsala Mire, Medema Mire).

Major influencing factors. This type of vegetation was observed in areas abandoned at least 20 years ago. Typically, the water table is high, the peat surface is wet (it may temporarily dry out in summers) or covered with shallow stagnant water. Various moisture conditions and water of various depths can be present in a single area. Vegetation composition and structure are influenced mainly by water table and by the amount of time passed since the cessation of peat extraction.

Succession. During the first 20–30 years after the cessation of peat extraction, the composition of *Sphagnum* species is usually poor. During the first 10–20 years, *Eriophorum vaginatum* may be nearly the only species, growing in shallow water or on wet peat which may become flooded at higher rainfall. Later, bryophytes start to establish, and *Sphagnum cuspidatum* is almost always the pioneer species. *Rhynchospora alba* may be dominant or co-dominant. Several decades later, after gradual formation of raised bog micro-relief (hummocks, depressions), the diversity of *Sphagnum* species increases, and also other bog species establish, such as *Oxycoccus* spp., *Drosera* spp. The dwarf shrubs occur on dryer elevations. The duration of the pioneer stage is influenced by the area size of peat field and the proximity of donor sites, as evidenced also by Quinty, Rochefort (2003). If the area is close to relatively undisturbed or intact mires, the recovery of vegetation and diversification of species composition occurs much faster. Development of peat-forming vegetation may start also after decades of being too dry if the drainage system is blocked and water table is raised. In such cases, the trees and dwarf shrubs perish and are being replaced by mire pioneer vegetation.

Later succession stage – formation of bog vegetation structure

Vegetation structure and composition. Compared to the species-poor early pioneer stage dominated by *Eriophorum vaginatum*, greater variety of structures develops later along with increase in species richness. Generally, rewetted cutaway peatlands lack macro-structures characteristic to intact raised bogs (cupola, ridges, pools, hummock-hollow micro-relief, etc.). They do not fully function as bog ecosystems, therefore they cannot be considered as an equivalent to intact peatlands, though they are on the way to recovery of bog structures and functions.

The vegetation is dominated by various *Sphagnum* species, such as *Sphagnum cuspidatum*, *S. magellanicum*, *S. rubellum*, *S. flexuosum*, *S. fallax*; other bryophytes species may include *Bryum* spp., *Cephalonia* spp., *Aulacomnium palustre*, *Warnstorfia* spp., *Polytrichum* spp. Common vascular plant species are *Rhynchospora alba*, *Eriophorum vaginatum*, *Drosera rotundifolia*, *Andromeda polifolia*.

Occurrence. Rather rare (e.g. Vārnēnu Mire (Figure 86, 87), Salaspils Mire, Ķemeri Mire, Labais Mire).

Figure 86. Recovery of bog vegetation in a wet depression in Vārnēnu Mire, where peat extraction was ceased ca. 40 years ago. Photo: M. Pakalne.

Figure 87. Micro-relief similar to hummocks with *Sphagnum rubellum* in raised bogs. Photo: M. Pakalne.

Major influencing factors. As observed in the surveyed abandoned areas, vegetation similar to raised bogs may develop only in depressions with constantly wet conditions, in relatively small areas. In rewetted cutaway peatlands with high water table, such peat-forming vegetation can develop in larger areas. Vegetation diversification is facilitated by proximity of undisturbed or slightly disturbed mires (donor areas). The longer the time since peat extraction, the richer the vegetation and it becomes more similar to natural bogs.

Succession. Bog vegetation may establish after rewetting of the former peat extraction areas following the intermediate stage with pioneer vegetation. In Latvia, the early stage of such vegetation has been recorded in the restored part of Lielsala Mire (Cupruns et al. 2013) and in extracted peatland in Ķemeri Mire (Ķuze, Priede 2008; Priede 2013). This type of vegetation development may be supported by re-introducing the target plant species, i.e. *Sphagnum* mosses (see Chapter 6.3.3).

Secondary dystrophic shallow water bodies

Vegetation structure and composition. Vegetation in inundated peatlands with residual acidic bog peat is usually species-poor. Emergent aquatic vegetation and floating mats develop only at the edges of water bodies (e.g. *Eriophorum vaginatum*, *E. polystachion*, *Carex rostrata* and some other sedge species, *Phragmites australis*). Surface of cutaway peatlands may be uneven, and such water bodies usually occupy the entire peat field, alternating between dryer elevations with pioneer vegetation or peat fields with secondary forests (Figure 79).

Occurrence. Rarely (e.g. Melnā ezera Mire, Medema Mire).

Major influencing factors. Overgrowing of deep water bodies (depth > 0.5 m) is mainly hindered by wave activity that does not allow anchoring of vegetation. The species composition is influenced by physical and chemical properties of water (acidic, nutrient-poor environment, low mineralization degree).

Succession. Considering the influencing factors (water depth, physical and chemical properties of water), open water bodies may persist for decades. Over many decades, the development of floating fen-type vegetation is expected, which may later transform into quaking bog and, over the course of several centuries, into raised bog. If the water level is lowered, pioneer vegetation typical for wet peatlands may develop, with *Eriophorum vaginatum* as the dominant species.

Cutaway peatlands with residual fen and transitional mire peat

The number of peatlands with residual fen and transitional peat is smaller than the number of peatlands with residual bog peat. Moderate to high degree of decomposition is characteristic to residual peat, and it is slightly acidic (pH ~4.5–7) to alkaline (pH ~7–8.2) (Priede et al. 2016). Due to highly variable environmental conditions and hydrological regime, a variety of vegetation can develop – from species-poor fens and floating fen-type blankets to species-rich alkaline fens. This makes generalisation of the vegetation types and their succession nearly impossible. Vegetation development scenarios (Figure 88) are significantly influenced by water table that is determined by the functionality of drainage system, peat extraction method and the subsequent after-use.

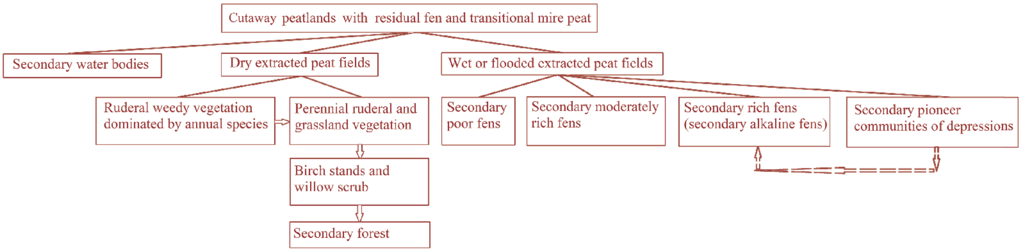

Figure 88. Spontaneous revegetation of cutaway peatlands with residual fen or transitional mire peat. Arrows indicate the directions of vegetation development; dashed arrow indicates unclear succession trend.

Secondary water bodies

Vegetation structure and composition. *Phragmites australis* is the dominant emergent aquatic macrophyte, often together with *Typha angustifolia*. Very rarely in alkaline water bodies with high mineralization rate *Cladium mariscus** was found (can form large monospecific stands). The floating-leaved vegetation is commonly composed of *Potamogeton natans*, *Nuphar lutea*, *Hydrocharis morsus-ranae*, *Nymphaea* spp. In the submerged vegetation *Potamogeton lucens*, *Myriophyllum spicatum*, *Batrachium circinatum* are common, rarely in alkaline water charophytes *Chara* spp. may be present.

Occurrence. Rare (e.g. Seda Mire (Figure 89), Kačori Mire, Strūžāni Mire, Praviņas Mire, Labais Mire, Briģi Mire, Smārde Mire).

Figure 89. Flooded cutaway peatland with mosaic of reedbeds and open water in Seda Mire. Photo: M. Pakalne.

Major influencing factors. The water bodies and vegetation of this type may develop in fens which have been extracted by various extraction methods leaving peat layer with varying thickness. In places where the residual peat layer is thin and the water body is primarily fed by groundwater, the water has high mineralization rate and high pH (Kļaviņš et al. 2011). The water level may have been intentionally elevated after peat extraction, or the area may be flooded because of non-functioning drainage system.

Succession. Most likely, *Phragmites australis* dominates at the pioneer stage and keeps the dominant role for a long time. Later, other species establish gradually, including floating-leaf and submerged plants.

Dry peat fields with residual fen and transition mire peatland

Pioneer vegetation and grassland vegetation

Vegetation structure and composition. In the surveyed peatlands with permanently dry or periodically dry residual fen peat, both early succession with a large proportion of annual plants was observed and later succession stages with grassland vegetation.

In the pioneer stage, species composition can be highly variable depending on the vegetation of the surrounding area. Mostly the vegetation is sparse. Characteristic species are *Calamagrostis epigeios*, *Phragmites australis*, *Typha angustifolia*, *Carex rostrata*, *Juncus effusus*, *Agrostis canina*. Vegetation with *Agrostis canina*, *Festuca ovina*, *Carex serotina*, *C. ornithopoda**, *Molinia caerulea*, *Polytrichum* spp. was observed in Strēļi, Praviņas and Ķirba Mires. Some patches may be dominated by *Molinia caerulea*. In all mires with sparse vegetation, invasive moss species *Campylopus introflexus*, sometimes forming dense mats, was observed (Figure 90).

In heavily drained areas abandoned 20–30 years ago, species of nutrient-rich soil may prevail; vegetation is tall, vigorous and species-poor with *Urtica dioica*, *Anthriscus sylvestris*, *Aegopodium podagraria*, *Cirsium arvense*, *Elytrigia repens*, *Calamagrostis epigeios*, *Rubus idaeus*, etc. (Figure 91).

Occurrence. Rarely (e.g. Valle Mire, Umuļi Mire, Strēļi Mire, Ķirba Mire, Praviņas Mire).

Major influencing factors. The formation of this vegetation type is primarily determined by dry conditions or highly fluctuating water table. In such conditions, the upper peat layer is highly decomposed with reduced water storage capacity. The water table may rise due to clogging of ditches or intentional rewetting – then development of peat-forming secondary fen vegetation is expected. Species composition is influenced by various factors, such as peat type and decomposition degree, pH, time passed since peat extraction, species composition in the surrounding areas, etc.

Succession. Over a period of a few years, vegetation of annual weeds turns into ruderal vegetation with perennial ruderals. Then, plant species of ruderalized grasslands take the dominating role. After a while, also trees and shrubs (*Betula* spp., *Salix* spp.) establish themselves, and, in a longer period of time, such degraded peatlands overgrow with secondary forest.

Figure 90. Carpet of invasive moss species *Campylopus introflexus* dominating in dry peat field in Ķirba Mire. Photo: A. Priede.

Figure 91. Vigorous tall vegetation with perennial ruderal plant species and grasses in Ķirba Mire. Photo: A. Priede.

Secondary forests

Vegetation structure and composition. Similarly as in extracted peatlands with residual bog peat, during a longer time period drained extracted peatlands with residual fen and transitional mire peat overgrow with secondary forest. Only a few examples of this vegetation type were found during the inventory. The tree layer is dominated by *Pinus sylvestris* and *Betula* spp., *Picea abies* can occur in the understory. Ground vegetation may be more variable than in peatlands with residual dry bog peat, though it can be very species-poor (e.g. nearly monodominant *Calamagrostis epigeios* or *Molinia caerulea*), in earlier stages it may be without any vegetation. Large stands of *Lycopodium annotinum** are common; also *L. clavatum** and *Huperzia selago** are found.

Occurrence. Rather rare (Rekšņi Mire, Strēļi Mire, Umuļi Mire, Ķirba Mire, Dedziņi Mire, Labais Mire).

Major influencing factors. Due to low, highly fluctuating water table, conditions are unfavourable for development of peat-forming fen vegetation; the drainage conditions are favourable for establishment of trees.

Succession. Secondary forest vegetation follows the early succession stages with ruderalized grasslands and scrub.

Wet cutaway peatlands with residual fen and transition mire peat

Secondary poor fens and floating mats

Vegetation structure and composition. Poor floating mat and fen vegetation (Figure 92) observed in a few extracted peatlands (e.g. Melnais ezers Mire, Cena Mire) with wet peat surface or shallow waters was composed of *Eriophorum vaginatum*, *E. polystachion*, *Carex rostrata*, *Phragmites australis*, *Juncus* *effusus*, *Carex canescens*, *Utricularia vulgaris*, *U. minor*, *Sphagnum cuspidatum*, *S. squarrosum*, *S. angustifolium*, *S. fallax*, *Warnstorfia* spp., *Drepanocladus aduncus*.

Figure 92. Fen vegetation in peatland of Melnais ezers Mire. Photo: M. Pakalne.

In areas fed by groundwater slightly richer in minerals (e.g. Labais Mire), plant communities with *Carex lasiocarpa*, *Carex canescens*, *C. diandra*, *Phragmites australis*, *Drosera* spp., *Comarum palustre*, *Naumburgia thyrsiflora*, *Galium palustre*, *Juncus effusus, J. conglomeratus*, several *Sphagnum* species, *Calliergonella cuspidata*, *Calliergon giganteum*, *Warnstorfia* spp. were observed. The upper layer of vegetation is formed by *Phragmites australis*; the shrub layer is composed of *Salix* spp., *Frangula alnus* and *Betula* spp.

Occurrence. Rarely (e.g. Cena Mire, Melnais ezers Mire, Labais Mire).

Major influencing factors. The vegetation of secondary poor fens develops as a result of gradual overgrowing of shallow waters or on wet peat with smooth water table fluctuations. The vegetation composition and structure is highly site-specific.

In lower depressions in Cena Mire and Melnais ezers Mire with this type of vegetation the environment is slightly acidic (pH 4–5.5) with low conductivity (35–80 µS/cm; unpublished data of PuReST project). However, these results cannot be generalised and extrapolated to other areas.

Succession. During several decades, floating mats with herbaceous plants and bryophytes develop, which can be considered the early stage of poor fens. In the subsequent succession, floating mats and fens will likely transform into transition mires and raised bog at the climax stage.

Secondary moderately rich fens

Vegetation structure and composition. The plant communities belonging to this vegetation type are highly variable. According to survey results, this vegetation is most often dominated by *Phragmites australis* and tall sedges *Carex elata*, *C. acuta*, *C. paniculata* (Figure 93). Vegetation of richer conditions (found in Elle Mire) was composed of *Deschampsia cespitosa*, *Festuca rubra*, *Filipendula ulmaria*, *Galium palustre*, *G. uliginosum*, *Lycopus europaeus*, *Lysimachia vulgaris*, *Peucedanum palustre*, *Viola palustris*, *Aulacomnium palustre*, *Calliergonella cuspidata*, *Climacium dendroides* and several *Sphagnum* species, e.g. *Sphagnum warnstorfii*, *S. rubellum*, *S. russowii*. The shrub layer is composed of *Betula* spp., *Salix* spp., and *Frangula alnus*.

Figure 93. Vegetation with *Carex paniculata* in a flooded cutaway fen area in Umuļi Mire. Photo: A. Priede.

Occurrence. Rarely (Elles Mire, Umuļi Mire, Ķemeri Mire).

Major influencing factors. This type of vegetation develops in peatlands with high water table. It has developed on wet peat after the clogging of ditches, perhaps due to beaver activity. In an earlier study by Priede et al. (2016), this vegetation type was described only in the cutaway peatland in Elle Mire. This peatland can be characterized as moderately rich fen with pH ~6.5 and relatively high conductivity

(130 μS/cm on average). However, results from one site cannot be generalized and extrapolated to other locations.

Succession. The vegetation type is rare, the course of succession is unknown.

Secondary rich fens (secondary alkaline fens)

Vegetation structure and composition. Vegetation is species rich. In early stages small sedges are dominant (*Carex serotina*, *C. flacca*, *C. flava*, *C. lepidocarpa*, rarely *C. scandinavica*), and *Phragmites australis*. There are also tall sedges, such as *Carex elata*, *C. lasiocarpa*, very rarely – *C. hostiana*. Species characteristic to the small sedge succession stage are *Juncus articulatus*, *Trichophorum alpinum*, *Eriophorum latifolium*, *E. gracile*, *Equisetum variegatum*, *Epipactis palustris*, *Dactylorhiza incarnata**, *Primula farinosa**, *Pinguicula vulgaris**, etc. Very rarely the communities are accompanied by *Liparis loeselii**[29] (Figure 97, two locations recorded) or co-dominated by *Schoenus ferrugineus** (Dedziņi Mire, Praviņu Mire, Ķirba Mire) (Figure 95). In bryophyte layer *Campylium stellatum*, *Scorpidium scorpioides*, *Drepanocladus* spp. prevail. Later, perhaps 30–40 years after cessation of peat extraction, development of nearly monodominant *Cladium mariscus** stands (Figure 96) is possible (in extracted peatlands recorded very rarely). In Ķirba Mire, plant community with *Carex bergrothii* and *Myrica gale** was found (Figure 94). After some time, the structural diversity (hummocks, hollows) increases.

Occurrence. Rarely (Dedziņpurvs Mire, Labais Mire, Praviņas Mire, Ķirba Mire, Strēļi Mire, Rekšņi Mire).

Major influencing factors. Primarily, the formation of such plant communities is determined by high groundwater table without large annual fluctuations, rich in calcium, and carbonatic bedrock. Species richness and composition is influenced by the surrounding flora and time passed since peat extraction cessation.

Succession. Initially, small sedge vegetation starts developing on wet, bare peat. Bryophytes are absent at the early succession stage, but their proportion increases gradually. Field observations suggest that more or less closed vegetation cover may develop within 20–30 years, while the bryophyte cover similar to that of natural calcareous fens develops in half a century or more. The species richness is gradually increasing over time. If *Cladium mariscus** is present in the surroundings or if it had grown in the mire before peat extraction, it can establish monodominant stands in a course of several decades. Such vegetation in several hectares large area has established only in Labais Mire; similar trend can be observed in Praviņas and Dedziņi Mires. Most probably, at high water table such fen communities can persist for centuries without turning into forest.

29 Included in the Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora, Annex II.

Figure 94. Secondary alkaline fen with *Myrica gale** and *Carex bergrothii*. Ķirba Mire. Photo: A. Priede.

Figure 95. Secondary alkaline fen with *Schoenus ferrugineus**. Dedziņpurvs Mire. Photo: M. Pakalne.

Figure 96. *Cladium mariscus** in Dedziņi Mire. Photo: M. Pakalne.

Figure 97. *Liparis loeselii* in Dedziņi Mire. Photo: M. Pakalne.

Secondary pioneer communities in wet depressions

Vegetation structure and composition. Pioneer communities with sparse vegetation cover composed of *Rhynchospora alba*, *Trichophorum alpinum*, *Oxycoccus palustris*, *Drosera rotundifolia*, *D. angustifolia*, *Lycopodiella inundata** (Figure 98), on drier elevations – *Calluna vulgaris*. In the bryophyte cover, *Sphagnum* spp., *Warnstorfia* spp., *Kurcia pauciflora*, *Mylia anomala*, *Riccardia* spp. were recorded.

Occurrence. Very rarely. Found only in Labais Mire, a block-cut peatland that was abandoned 50–60 years ago. The pioneer community covers small patches (a few square metres), occurs in mosaic with other plant communities.

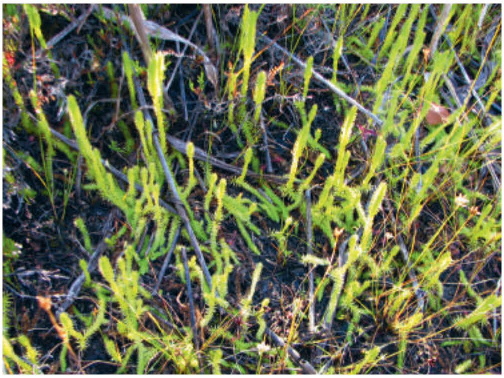

Figure 98. Very rare plant community in Latvia composed of *Lycopodiella inundata, Drosera* spp.*, Rhynchospora alba* in Labais Mire. Photo: A. Priede.

Major influencing factors. Primarily, the formation of this vegetation type is determined by continuously wet, shallow residual well decomposed fen peat. This plant community is only found in one mire in Latvia, therefore it is not possible to evaluate the possible variations in environmental conditions. Residual peat in this area is thin, and the plant community grows partly on sand which has been exposed during peat extraction. Soil water pH value varies from 4.3 to 4.7, conductivity is 57–260 µS/cm (PuReST project, unpublished data).

Succession. This plant community is a pioneer community that depends on moderate disturbances (such as frost heave, inundation, soil disturbances by wild animals, etc.). As observed in the only known locality, if disturbances are absent, it is outcompeted by *Rhynchospora alba*, *Sphagnum* spp., *Cladium mariscus*, and the pioneer community disappears.

Potential use of spontaneous revegetation in rehabilitation of cutaway peatlands

Lessons learned during the LIFE REstore project and other studies of abandoned cutaway peatlands in Latvia (PuReST, 2014–2015; Priede, Silamiķele 2015; Priede et al. 2016; Priede, Mežaka 2016) suggest that the basic requirement for successful recovery of peat-forming mire vegetation is high water table. Not surprisingly, the same was concluded by numerous earlier studies in many countries, e.g. in Canada (Quinty, Rochefort 2003; Gagnon et al. 2018), Germany (Sliva, Pfadenhauer 1999), Estonia (Karofeld et al. 2016A, 2016b), etc.

The results of LIFE Restore, as well as studies in other countries (Chapman et al. 2003; Poulin et al. 2005; Triisberg et al. 2011) show that restoration of block-cut peatlands may be easier with higher probability of success. In many cases, these areas have already well recovered themselves without targeted rehabilitation measures. It has been facilitated by use of less destructive peat extraction methods, as large homogeneous heavily drained territories were not created. Often, "islands" with mire vegetation were preserved which later served as donor areas for vegetation self-regeneration. Nowadays, the moisture conditions in block-cut areas abandoned in the mid-20th century are appropriate for mire vegetation. Nevertheless, there are some large peat quarries which are problematic – they are deep and drain the surrounding peatland, and the peat removal has exposed the mineral ground that hinders the recovery of mire vegetation.

In terms of structural diversity and ecosystem functions, the cutaway peatlands will not become equivalent to intact mires during hundreds of years. However, they can host peat-forming vegetation that leads to gradual recovery of peat accumulation, carbon sequestration and other peatland ecosystem functions. Considering that peat extraction destroys mires, rehabilitation by reintroducing mire vegetation or creation of water bodies are the only ways to partially compensate for loss of these natural ecosystems. However, water bodies are considered as a less climate-friendly alternative, as they are significant sources of methane emissions, at least in the early stage (Wilson et al. 2008). Other reclamation measures would only be applicable if rehabilitation is not possible for some compelling reason. Currently in Latvia, there is lack of mechanisms which would promote rehabilitation of wetlands (called *renaturalizācija* in national legislation) in cutaway areas. There is no compensation mechanism in case if surrounding commercial forests or agricultural lands would be adversely affected by rewetting. There is also lack of understanding, knowledge and experience. However, the only way to gain experience in Latvia is by experimenting and monitoring the progress and results. Such experiments would serve as demonstration sites to learn both successful experiences and mistakes and encourage future experiments.

Rehabilitation of the former peat extraction areas must be always well planned. If a cutaway peatland is left for natural succession with a functioning drainage system, it by no means can be considered as rehabilitation of peatland ecosystem. Rehabilitation means that the environment must be prepared and mire conditions must be created. So, first of all, drainage influence must be prevented, otherwise recovery of mire vegetation and functions is not possible, or it would be slow, in case if the ditches are blocked by beavers or would gradually overgrow. However, in the meantime the cutaway peatland would likely overgrow with forest, and mire restoration would become impossible or it would be complicated and costly. Such examples in Latvia can be found in extracted peatlands abandoned during the Soviet period.

Compared to several other after-use types, rehabilitation does not require further permanent investments, such as maintenance of drainage system, fertilization and watering. In this way, not only sustainable, carbon-binding ecosystems can be created, but also ecosystems that are important for biodiversity conservation.

Conclusions

- ✔ The course of spontaneous revegetation is determined by a combination of various conditions and factors – peat extraction method, water table, physical and chemical properties of the residual peat and water, depth of residual peat, mineral ground below the peatland, as well as characteristics of the surrounding vegetation. All of these factors must be taken into account when planning rehabilitation of cutaway peatlands.
- ✔ As suggested by LIFE REstore and similar inventories in Latvia, vegetation succession on acidic raised bog peat may be generalized, as the variation of vegetation types and the course of succession is low. However, it is difficult or even impossible to generalize and to predict vegetation development in cutaway peatlands with residual fen peat or residual transitional mire peat. In such cases, large variation of abiotic conditions and vegetation is possible. This should also be taken into account when planning the rehabilitation measures – the result will be more difficult to predict.
- ✔ Development of mire vegetation in cutaway peatlands is possible only if high water table with slight fluctuations can be achieved. The mean annual water table should not be lower than 0.3 m below the peat surface. Recovery of mire vegetation is impossible in case of low water table in combination with high annual fluctuations that leads to extreme conditions on peat surface (heating up in summer, suffering from frost heaving and wind erosion in winter). In these circumstances, only a few plant species can survive.
- ✔ During the inventory, several examples of successful spontaneous revegetation were found both in peatlands with residual bog peat and in mires with residual fen and transitional mire peat. This suggests that rehabilitation can be successful if drainage influence is prevented.
- ✔ Inventory results by LIFE REstore and similar studies show that at least several decades are

necessary for recovery of mire vegetation composed of species characteristic for the particular conditions, including bryophytes.

- ✔ Leaving a cutaway peatland with a functioning drainage system as it is to allow natural succession cannot be considered rehabilitation, as the conditions are not suitable for peat-forming mire vegetation. Consequently, the peat accumulation and other mire ecosystem functions, including carbon sequestration, are not restored.

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4.5. LIFE REstore database on areas affected by peat extraction

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Summary

In the period from 2016 to 2018, areas affected by peat extraction were inventoried within the LIFE REstore project. Identified territories were mapped, and a geospatial data set was created that includes information on the harvested peatlands, their location, area size, current status, peat properties, hydrological regime, etc. Information obtained during the inventory is freely available in the Latvian Nature Data Management System OZOLS, in a particular section: https://restore.daba.gov.lv/public/lat/datu_baze1/. The database is an important tool for planning the use of peatlands, including reclamation of abandoned harvested peatlands, as well as for the implementation of requirements set in Regulation 2018/841 of the European Parliament and of the Council (30 May 2018), or EU-LULUCF Regulation.

Using data of the situation on January 1, 2016, 237 sites affected by peat extraction were identified in 180 peatlands, with a total area of 50,179 hectares. Of these areas, peat is currently being extracted in ~15,000 ha large area; ~17,000 ha of harvested peatlands have been reclaimed, while ~18,000 hectares are harvested, abandoned peatlands where reclamation is necessary. In many of these abandoned areas there are unused peat resources left. If peat extraction is resumed then reclamation must be carried out as required by legislation.

Introduction

On May 30, 2018, Regulation 2018/841[30] of the European Parliament and of the Council (LULUCF Regulation) came into force. Its aim is to establish the obligations for the Member States of the European Union and the accounting rules for greenhouse gas (GHG) emissions and carbon dioxide (CO_2) captures in the land use, land-use change and forestry sector in 2021–2030. Among other things, the LULUCF Regulation obliges Member States to keep track of GHG emissions and CO_2 removals starting from 2026, by preparing and providing information on managed wetlands. Peat extraction is the most important source of GHG emissions in the category of managed wetlands (GHG emissions from areas where peat is being extracted and which are not reclaimed after completion of peat extraction).

The LULUCF Regulation was developed and adopted between June 2016 and May 2018. During the process of drafting and approving the regulation, various data on influence of peat industry was necessary for the analysis of situation in Latvia. LIFE REstore project made a significant contribution to this work.

In Latvia, peat has been harvested since 17th–18th century (Šnore 2013). Nowadays, peat extraction is one of the types of entrepreneurship in Latvia. Almost all of the peat extracted in Latvia is being exported to foreign countries. Between 2015 and 2017, an average of 1.5 million tonnes of peat was extracted every year (Centrālā statistikas pārvalde 2018). It is four times more than in year 2000, and five times less than in 1965.

The monitoring of peat extraction is carried out by State Environmental Service, which issues licenses for the use of subterranean depths, including peat extraction. However, the situation reflected in the licensing of peat extraction is different from the situation which can be observed in field. Therefore, in order to assess the situation in Latvia and the total number and condition of areas affected by peat extraction, a database was developed within LIFE REstore project.

In 2016–2018, LIFE REstore project identified and inventoried peat extraction areas in order to document and recognise all such areas in Latvia, to obtain information on their compliance with managed wetlands in terms of LULUCF Regulation[31], to obtain information on peatland characteristics and to prepare a geospatial data set. This chapter provides an overview of the contents of the database and the methods which were used for its development. More about the results of 78 geological inventories included in the database – see Chapter 4.2 of this book; on the results of vegetation inventory – Chapter 4.4; on the results of soil analysis and greenhouse gas measurements – Chapter 3.

Material and methods

In order to identify the areas affected by peat extraction in Latvia, the first step was to identify such areas using orthophotomaps (image series from 1994–1999, 2001–2005, 2005–2008, 2010–2011, and 2013–2015), as well as Google Earth's publicly available satellite imagery library (*QGIS QuickMapServices*). In some cases, *Google Timelapse* service[32] was used, as well as topographic maps of Latvia at scale 1:10,000 (Cycle 4[33]). In order to reduce the area size which had to be surveyed, data on peat extraction and extracted areas were compared with data of Latvian Environment, Geology and Meteorology Centre[34] on peatland distribution and cover in Latvia. Territories outside the boundaries of

30 Regulation 2018/841 of the European Parliament and of the Council of 30 May 2018 on the inclusion of greenhouse gas emissions and removals from land use, land use change and forestry in the 2030 climate and energy framework, and amending Regulation (EU) No 525/2013 and Decision No 529/2013/EU.

31 Regulation 2018/841 of the European Parliament and of the Council of 30 May 2018 on the inclusion of greenhouse gas emissions and removals from land use, land use change and forestry in the 2030 climate and energy framework, and amending Regulation (EU) No 525/2013 and Decision No 529/2013/EU. According to article 2.1.b, managed wetlands are: wetland remaining wetland; settlement or other land, converted to wetland; wetland converted to settlement or other land.

32 Google Earth Engine, https://earthengine.google.com/timelapse/ .

33 Latvian Geospatial Information Agency, https://kartes.lgia.gov.lv/karte/.

34 Register of Mineral Deposits, Latvian Environment, Geology and Meterology Centre, http://www2.meteo.lv/kuudra/purvi_uc.kmz.

these peatlands were inventoried only if indicated in municipal survey, expert interviews, and by peat industry representatives.

At the same time, all local governments in Latvia were surveyed, asking for information on existing or former peat extraction sites within their territories. Several local governments provided exact details on present and former peat extraction within their territories. Based on this information, previously unknown peat extraction areas were detected.

Expert interviews were also used for the inventory. In the interviews with experienced professionals of peat extraction and forestry, individual areas affected by peat extraction were identified, as well as the names of these areas, their boundaries, and other useful information. Information prepared by association "homo ecos:" in 2016 in project "Analysis of quality of data on peat extraction areas in Latvia, preparation of recommendations for their improvement and use for preparation of national strategy documents" (Jansons 2016) was used. Experts from "homo ecos:" conducted an assessment of peat deposits, including areas that used to be extracted, but extraction had been discontinued and may not be completed.

The obtained data on all areas degraded by peat extraction were compared with the information of State Geological Fund of Latvian Environment, Geology and Meteorology Centre and also with information available in the publication of Peat Fund (Kūdras fonds) (Latvijas valsts meliorācijas projektēšanas institūts 1980). Detailed information on 95 harvested peatlands was obtained from State Geological Fund. Information on seven peat extraction sites was obtained from landowners and operators.

Information on 78 peat extraction areas was obtained in field work (see Chapter 4.2). During the field work, peat samples were collected, and photographs of samples and areas were taken. Thickness of the residual peat layer was determined, type of the upper peat layer (up to 0.3 m depth), degree of decomposition, soil water pH value and groundwater table at the time of the survey were measured. Drainage systems were surveyed, and the type of sediments below the peat were analysed.

After identification of the areas on map, the ongoing processes and size of the areas (hectares) were analysed using three categories: areas where peat extraction takes place; (2) areas that are reclaimed after peat extraction; (3) areas that are not reclaimed after peat extraction.

Size of the areas (hectares) of peat extraction sites were determined using orthophotomaps of 2013–2015. All rewetted areas and areas that have been converted into other land use types (water bodies, forests, agricultural lands, built-up areas) were considered as reclaimed.

In order to determine the former peat extraction sites, which have been reclaimed by creating water bodies, the topographic map of Latvia (1:10,000, 2010–2011) was used. Forestry areas were identified using the State Forest Register maintained by State Forest Service, additionally using *Sentinel II* satellite images[35] to distinguish afforested areas which were not included in the Forest State Register. Agricultural lands, including large cranberry, and lowbush and highbush blueberry plantations, were determined using Rural Database of Rural Support Service (crop codes in 2015). The built-up areas were determined using the topographic map of Latvia (1:10,000; 2010–2011).

Areas which were identified as harvested peatlands but are currently not used for peat extraction or that were not known to be reclaimed (including rewetting) were considered as unreclaimed, degraded peatlands.

In addition to the inventory work, a number of parameters characterizing the areas influenced by peat extraction were obtained. They were necessary to get a more general view on degraded peatlands which were not reclaimed after the completion of peat extraction, including information on the owner of the site, discharge of drainage network, distance to the nearest roads, distance to the nearest settlement, etc.).

35 European Space Agency, http://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Sentinel-2.

The information was processed using *QGIS*[36], *GRASS GIS*[37] and *SAGA GIS*[38] programs, including *QGIS* which was used for marking borders of polygons. *QGIS* tool *Topology Checker* was used in spatial data processing steps to correct the errors in polygon distribution and to determine polygon size and other geometric parameters. *Join Attributes by Location* tool was used for combining the attribute tables of different spatial data layers and for storing spatial data.

Programs *GRASS GIS* and *SAGA GIS* were used to run the algorithms. *SAGA GIS* was used to clip polygons according to information available in various databases (*Intersect* and *Polygon Clipping* tool). Topology errors were corrected after polygon clipping using *Intersect* and *Polygon Clipping* tool. After clipping, polygons were merged again, to determine the actual total area and make sure that there were no geometric errors created by the process of clipping. *GRASS GIS* program was also used for raster data analysis (*Raster Calculator* tool). More information about the methods used for analysing the cartographic material is available in the LIFE REstore report "Inventory of degraded peatlands and creation of a database" (LIFE REstore 2018, in Latvian).

The situation in peat extraction areas change every year. There are territories where peat extraction fields are being extended, and territories where the former peat extraction areas are being reclaimed. In order to analyse data in such a changing situation, data describing the situation on January 1, 2016 were used.

In the inventory process of areas affected by peat extraction, a criterion was set that each area should be large enough to be identified by orthophotomaps. This means that areas that were identified but were smaller than two hectares were excluded from further analysis. Such small peat extraction areas are created, for example, when peat is harvested for personal needs, without establishment of proper infrastructure.

There were cases when peat had been extracted in the same peatland (peat deposit) in several, geographically separated locations. Sloka Mire (north of the Kūdra railway station in Jūrmala City) is a typical example where peat was extracted in several quarries, creating several non-interconnected peat extraction fields. In such cases, all such areas within the same peatland were aggregated in the analysis, and assumed as a single area. In geospatial data set prepared within the inventory, every harvested peatland is shown according to its actual location in nature.

Results and discussion

The https://restore.daba.gov.lv/public/lat/datu_baze1/ (Nature Conservation Agency 2019) developed by the LIFE REstore project is the first source of this kind of data, where information on harvested peatlands is compiled. The database was created using *MS Excel* software. To make the data available for everyone interested, the results have been published in the GIS-based Nature Data Management System OZOLS.

The data available in the database are extensive and can be used for various purposes. For example, the information from LIFE REstore database was processed to identify areas that do not comply with the requirements of LULUCF Regulation, as well as to develop and recommend the most appropriate after-use scenarios for harvested peatlands.

In total, 237 areas affected by peat extraction were identified and their borders delineated. In the database, specific areas can also be found by name, though the same site may have several names. When exploring each peat extraction area in detail, it is possible to determine how much of the total area

36 QGIS Development Team 2018. QGIS Geographic Information System. Open Source Geospatial Foundation Project, https://www.qgis.org/en/site/.

37 GRASS Development Team, 2015. Geographic Resources Analysis Support System (GRASS) Software, Version 6.4. Open Source Geospatial Foundation. Electronic document:, https://grass.osgeo.org/.

38 Conrad O., Bechtel B., Bock M., Dietrich H., Fischer E., Gerlitz L., Wehberg J., Wichmann V., Böhner J. 2015. System for Automated Geoscientific Analyses (SAGA) v. 2.1.4, Geoscientific Model Development 8, http://www.saga-gis.org/en/index.html.

is currently being extracted, how much or the area is reclaimed, and how much – abandoned without reclamation. Using additional database tools, it is possible to perform automatic calculation of the proportion of areas of the abovementioned types, as well as to use different base maps.

237 areas affected by peat extraction, as identified by the project inventory, are located within 180 peatlands (peat deposits). For each surveyed peatland, information on the most recent peat extraction method, licence areas and land owners is also available. The attribute information for each peatland include also data about the distance to the nearest water bodies where water from the extraction fields is being discharged, distance to nearest road of national importance, as well as the distance to the nearest protected nature area. Several database fields characterize peat properties, hydrological conditions and sediments underlying the peat deposits.

Peat extraction areas with a total area of ca. 50,000 hectares were identified. Out of them, peat extraction is being continued in ca. 15,000 hectares (30%). Approximately 17,000 hectares (34%) are reclaimed or reclamation measures are being currently implemented (regeneration of peat-forming vegetation, flooded areas, forests, grasslands, built-up areas, berry plantations, etc.). About 18,000 hectares (36%) are degraded, unreclaimed territories. In numerous areas, the peat deposit is completely extracted, whereas there are many areas with large residual peat resources left. Here, if peat extraction is resumed, reclamation must later be carried out in accordance with the national legislation (see Chapter 6.1).

The proportion of various types of peat extraction areas in Latvia is presented in Table 20.

Table 20. Summary of inventory results.

Areas affected by peat extraction (from 19th to 21th century)							
Peat extraction, situation on 01/01/2016	Reclaimed areas and areas where reclamation is being implemented						Degraded areas where reclamation is necessary*
	Self-regenerating peatlands (former block-cut areas)	Flooded areas	Forests	Grasslands	Built-up areas	Berry plantations	
	2 380	7 110	6 823	363	266	219	
15.008	17.161						18.010
50.179							

** In many of these areas, industrially usable resources are left. If peat extraction is resumed, the areas must be later reclaimed in accordance with requirements defined in the legislation.*

The inventory of peat extraction areas has shown that the sites are not homogeneous, and many of them host several land use types, such as water bodies, forests, and abandoned, unreclaimed peat fields. Also the site conditions are diverse – various residual peat thickness, physical and chemical properties of peat, peat decomposition degree, and others. Such nuances within an individual peatland are not shown in the database.

Out of 180 harvested territories, 90 territories had valid peat extraction licenses on January 1, 2016. Peat extraction was continued in 71 territories. In 107 sites, peat extraction has been completed or discontinued.

In total, there are 18,010 ha of post-harvested peatlands which are not reclaimed, and where the type of further land use must be selected. Information on the after-use scenarios in areas affected by peat extraction and their assessment is provided in Chapter 6.2 of this book.

Using the data of Peat Fund (Latvijas valsts meliorācijas projektēšanas institūts 1980), the peat type in each peatland before the peat extraction was identified. In 77 cases it was raised bog, but in 29 cases – fen. In the remaining 74 cases, there were several peat types (fen, transitional mire, raised bog) in a single peatland area.

The largest area affected by peat extraction in Latvia is Seda Mire – it covers more than 5100 ha. The largest area where peat extraction is currently being continued is Skrebeļu-Skrūzmaņu peat deposit in Rožupe rural territory of Līvāni municipality (> 1000 ha). The average area of one active peat extraction site of is just over 200 hectares. The smallest active peat extraction site covers 13 hectares. Most peat extraction areas are smaller than 100 ha, and there are only a few with an area of over 500 hectares. The distribution of harvested peatlands by their amount and area size is shown in Figures 99 and 100.

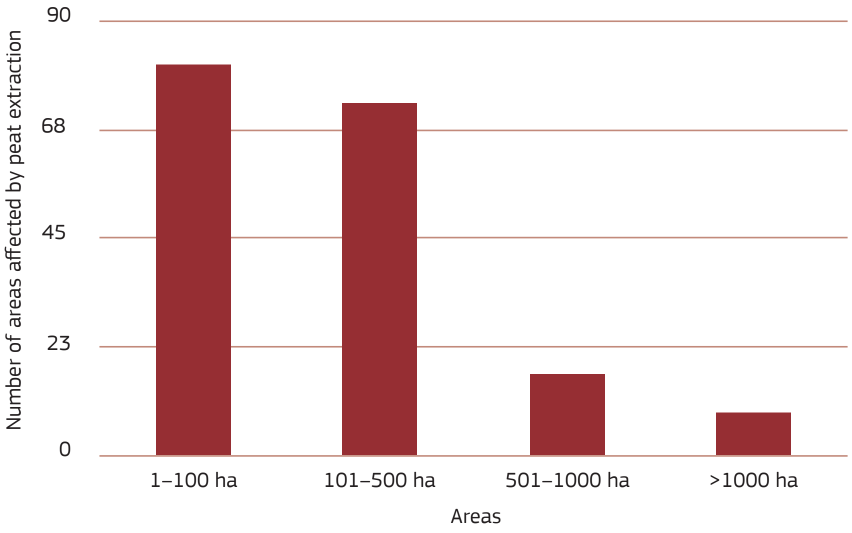

Figure 99. Number of peat extraction sites by their area size.

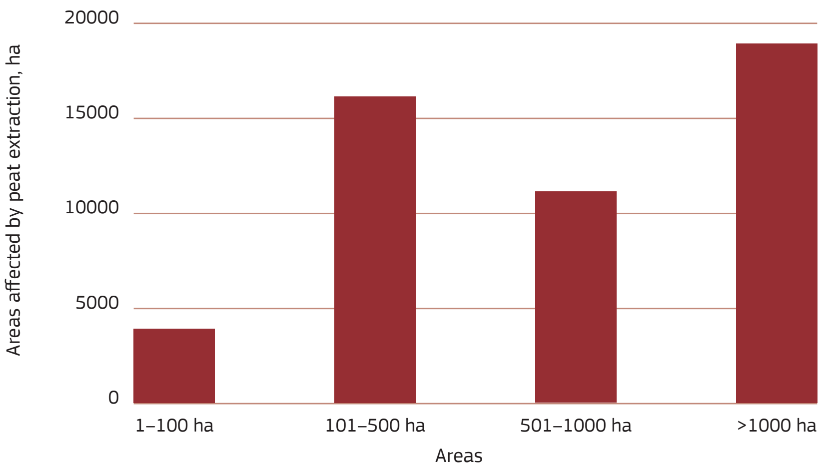

Figure 100. Total land area affected by peat extraction (ha) by area size.

There are 25 peat extraction areas which are located in protected nature areas of various categories, for example, Vasenieku Mire (Stiklu purvs Nature Reserve), Nida Mire (Pape Nature Park), Ķemeri Mire (Ķemeri National Park), Cena Mire (Cenas tīrelis Nature Reserve), Ķiguļu Mire and Lielais Unguru Mire (both in Gauja National Park). Other 21 harvested peatlands are located in a distance closer than 1 km from protected nature territories, for example, Sārnate Mire (Sārnates purvs Nature Reserve), Umuļu Mire (Ventas ieleja Nature Reserve), Korkuļu Mire (Korkuļu sausgultne un pazemes upe Nature Monument), Rinka Mire (Gauja National Park).

Starting from 2026, Latvia has to keep accounts of GHG emissions and CO_2 removals in accounting category of managed wetlands (also for peat extraction) under the LULUCF Regulation. Peat extraction areas identified by LIFE REstore project (harvested peatlands that have not been reclaimed after peat extraction) cause a significant increase in the total balance of GHG emissions. It is possible to compensate for this by reclaiming areas where peat extraction no longer takes place. Reclamation of areas without valid license for the use of subterranean depths (as identified in database) is a priority. In such areas, peat extraction is completed, but due to functioning drainage networks the peatland ecosystems or other wetland types are not capable to regenerate without targeted rehabilitation measures. It is also necessary to ensure that the requirements of legislation are followed and that the areas are reclaimed as soon as possible after completing the peat extraction. According to the LULUCF Regulation, within 20 years after the reclamation the land accounting category will be completely changed according to the selected after-use scenario, from the category of managed wetland to another. In case if degraded territories will not be reclaimed, and new peat extraction sites will be created or existing sites will be enlarged, an even more negative effect will be achieved in the context of GHG emissions.

The Law on Subterranean Depths determines an obligation for peat extractors to ensure reclamation of degraded peatland at their own expense, within the time limit specified in the license. However, there is no peat extractor for about half of the territories abandoned long time ago, since the extraction has taken place before Latvia regained its independence in 1991. Reclamation of such areas should be as a joint work that involves the state, municipalities and landowners. Using the LIFE REstore database, it is possible to identify municipalities where this issue can be topical and solutions should be sought in the nearest future.

The database is fully usable only if the information is current and relevant to the actual situation. In framework of LULUCF Regulation, information on managed wetlands, including peat extraction areas and degraded, unreclaimed peatlands, must be updated regularly and provided annually to the European Commission. Therefore, regular and systematic updating of information will be necessary. The situation is complicated by the fact that peat extraction is dynamic. Areas of peat extraction, as well as areas of reclaimed territories change constantly over time. When updating the database, all areas affected by peat extraction should be re-evaluated, and new peat extraction areas should be included in the data set.

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5. PEATLAND ECOSYSTEM SERVICES

Aija Peršēvica, Agnese Jeņina

5.1. Peatland ecosystem services in the LIFE REstore demo sites

Summary

Ecosystem services are understood as all benefits that humans can gain from ecosystems. By using the ecosystem services approach, it is possible to demonstrate the benefits of the ecosystem and, at the same time, model the development scenarios of the territory by comparing both the potential benefits and the expected risks, and make reasoned decisions.

On the one hand, natural peatland ecosystems can ensure biodiversity and regulate climate, water and nutrient cycles. On the other hand, peat is an important resource that can be used both in energy production, agriculture, production of insulation materials and for other purposes. By evaluating ecosystem services, it is possible to gain a more complete picture of all kinds of benefits provided by an ecosystem, to compare them, and make sustainable decisions about future use and management of a particular area.

Ecosystem services were evaluated in five LIFE REstore demo sites. Four of them were located in cutaway peatlands, and their after-use scenarios included tree planting (afforestation); establishment of highbush blueberry and large cranberry plantations, as well as Sphagnum reintroduction. The fifth site where rewetting was carried out was a raised bog bordering with a peat extraction area. Ecosystem services provided by these areas were evaluated before reclamation and rewetting and estimated for three different time periods. The ecosystem valuation matrix developed by B. Burkhard and co-authors was used for the assessment.

It was concluded that natural areas provide significantly higher regulating services than areas affected by peat extraction. Comparing the future development of LIFE REstore demo sites in terms of ecosystem services, afforestation is the most valuable scenario in the perspective of both five and 25 years, as it can provide both high-valued regulating services and high-valued provisioning services compared to other after-use types.

Introduction

The concept "ecosystem services" is largely explained as benefits that people gain from ecosystems (Millenium Ecosystem Assessment 2005). Expanding this definition, it can be concluded that humanity and its well-being depend on well-functioning ecosystems and the services they provide. In the last decade, the concept of ecosystem services has been expanded to include the contribution of ecosystem structures and functions to human well-being, which develops in combination with the contribution of human activities to the ecosystem (Burkhard et al. 2012a).

Better understanding of nature and its resources from the perspective of human as a beneficiary, is essential in order to protect ecosystems and their provided services more effectively (Brauman et al. 2007). The approach of ecosystem services is one of the possibilities which enable demonstration of the close link between human well-being and ecosystems (Fisher et al. 2009).

Evaluation of ecosystem services has a strategic role in the regional context, as indicated in European Union Biodiversity Strategy for the period until 2020. One of the tasks of this strategy is to map and assess the condition of ecosystems and their services by 2014. By 2020, the economic value of ecosystem services must be evaluated (European Commission 2011).

The most important functions of peatland ecosystems, in the context of their provided ecosystem services, are biodiversity conservation, climate regulation, water purification, and the sustainable development of humanity, for example by providing recreation and outdoor education opportunities (Bonn et al. 2008; Kimmel, Mander 2010). If ecosystems are significantly modified by human activities, their ability to provide ecosystem services is reduced (Burkhard et al. 2009). Based on the assessment of ecosystem services, it is possible to clearly compare both the benefits of peat extraction and the potential benefits of reclamation and restoration of degraded peatlands.

In many countries, evaluation of ecosystem services is already used as one of the tools for planning of sustainable spatial development (for example, in the United Kingdom (Albon et al. 2011), Finland (Jäppinen, Heliölä 2015), China (Standford University, *Natural Capital Project*), and others). This approach allows assessing both the benefits and the potential risks of the decisions taken.

The purpose of the LIFE REstore ecosystem service assessment was to analyse the benefits provided by the reclamation and restoration measures implemented in project demo sites, as well as to assess their ability to provide ecosystem services over five, 25 and 50-year periods.

Methods of assessing the ecosystem services

According to the international classification of ecosystem services (*Common International Classification of Ecosystem Services*), ecosystem services are assigned to three categories:

- ✔ **provisioning and supply** – materials and resources (both for food and for energy purposes) that people gain from ecosystems;
- ✔ **regulation and maintenance services** – services provided by ecosystems through their regulation functions which are affecting human health, safety, or comfort (regulation of air and soil quality, flood control, control of disease agents, etc.);
- ✔ **cultural services** – the intangible benefits provided by ecosystems that affect people's psychological and mental condition (active or passive recreation, environmental education, etc.) (CICES 2018).

Assessment of ecosystem services is difficult due to complexity of the topic and the need for a universal and easy-to-use method (Crossman et al. 2013).

In Latvia, the assessment of ecosystem services is relatively new approach. It has been used in a number of projects, such as: (1) *Assessment of Ecosystems and their Services for Nature Biodiversity Conservation and Management*, LIFE13 ENV/LV/000839, LIFE EcosystemServices (Nature Conservation Agency, 2014–2020); (2) *Integrated Planning Tool to Ensure Viability of Grasslands*, LIFE13 ENV/LT/000189, LIFE Viva Grass (Baltic Environmental Forum, 2014–2018); (3) *Impact of Forestry on Forest and Related Ecosystem Services* (Latvian State Forest Research Institute "Silava", 2016–2020; Lībiete 2016), etc.

All of these projects used the same approach for mapping and evaluation of ecosystem services – a Matrix-Assessment of Ecosystem Services Provision developed by German researcher B. Burkhard and co-authors (Burkhard et al. 2009, 2012a, 2012b, 2014) (Figure 101).

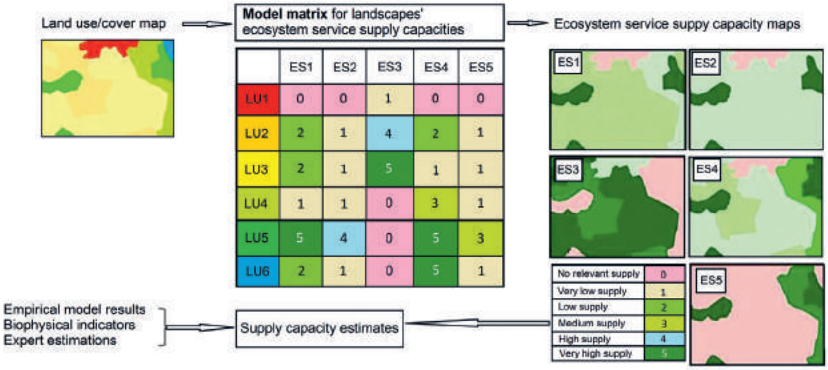

Figure 101. Scheme of the matrix model of ecosystem services. Source: Jacobs et al. (2015).
Abbreviations: LU – land use/cover, ES – ecosystem service.

By using a unified approach for the assessment of ecosystem services, it is possible to compare data and to develop a common vision and analysis on ecosystem services which are available in Latvia. Similarly to the abovementioned projects, the LIFE REstore project also used the Ecosystem Services Assessment Matrix, developed by Burkhard et al. (2009). According to this approach, ecosystem services provided by a particular land cover type are analysed spatially.

Ecosystem functions and services are strongly influenced by land use. For example, one of the main functions of agricultural land is to provide the provisioning services with the highest possible value.

Assessment of the ecosystem services within the LIFE REstore project included the activities listed below:

- ✔ 1. Determination of land cover types and their areas in the LIFE REstore demo sites.
- ✔ 2. Determination of ecosystem services and their indicators in demo sites that are summarized in Table 21. For evaluation of the ecosystem services, it is essential to select and develop indicators that must be: (a) reliable and capable of projecting complex relationships; (b) measurable and transparent; (c) relevant to particular purpose (in this case – assessment of peatland ecosystem services) (Feld et al. 2009). The indicators used in LIFE REstore project were selected both on the basis of literature studies (including the common international classification system of ecosystem services), and also on the experience and estimations of experts on parameters which could be used for evaluation of a particular ecosystem service.
- ✔ 3. Evaluation of ecosystem service indicators was provided by experts with in-depth knowledge and experience in the following fields: mires, freshwater and other types of wetlands, forests, mammals, birds, invertebrates, geology, hydrology. By evaluating ecosystem service indicators, experts provided a detailed description of each indicator, its baseline data, and assumptions which were used to determine the value of a particular indicator:
    - To ensure that data provided by experts on various ecosystem services are highly comparable, a list of indicators developed by LIFE EcosystemServices project was used (Annex 2). This list provides basic information on the data and assumptions, as well as the indicator classification of the ecosystem services indicator. It also defines which parameters can be used for the assessment on whether the value of the ecosystem service is low or high.
    - Using the developed indicator data sheet, experts evaluated the ecosystem service of every land cover type on a scale from zero to five (0 – ecosystem service not provided; 5 – very high value of ecosystem service).
    - Experts based their assessment on knowledge, literature, experience, field surveys, interviews, observations, measurements, and other research methods.
    - For the evaluation of cultural services and the evaluation of pollination and seed dispersal, the indicator sheets developed by the LIFE EcosystemServices project were used, which were later adapted to be used in LIFE REstore project demo sites.
- ✔ 4. Matrix-assessment of ecosystem services for every after-use scenario implemented within LIFE REstore project can be seen in Annex 3.

Table 21. Ecosystem services and their indicators identified in the LIFE REstore demo sites and in their surroundings.

Category	Division	Group	Class	Indicator	Measurement unit
Provisioning	Nutrition	Biomass	Cultivated crops	Crops of large cranberries/ highbush blueberries	t/ha/year
			Wild plants, mushrooms and their outputs	Crops of wild berries	kg/ha/year
			Wild animals	Amount of game	Relative number of game animals per 100 ha
	Materials	Biomass	Fibre and other materials from plants, algae and animals, for direct use or for processing	Volume of timber	m^3/ha/year
				Sphagnum mosses	Cover (%)
				Raised bog peat for horticultural use	Thickness of peat layer (m)
				Fen peat for horticultural use	Thickness of peat layer (m)
				Limonite	t
				Amount of collected medicinal plants	Number of species
		Water	Water for agricultural use	Water for growing of large cranberries/highbush blueberries	m^3/ha/year
	Energy	Biomass-based energy sources	Plant-based resources	Wood biomass for energy production	m^3/ha/year
Regulation and maintenance	Mediation of pollution, toxics and other nuisances	Processes in ecosystems	Storage and accumulation in ecosystems	Soil ability to bind and accumulate nutrients	Coefficient
			Dilution of pollution	Amount of pollutants and aerosols diluted by ecosystem	Coefficient
			Mediation of noise	Woodland density	Index
	Mediation of flows	Mass flows	Erosion control	Vegetation cover providing the erosion protection	Vegetation cover (%)
		Liquid flows	Maintenance of water cycling	Sediment water capacity and water storage capacity	Complex parameter
	Maintenance of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	Pollination and seed dispersal	Biodiversity and abundance of insect pollinators	Number of species and individuals per hectare
			Maintenance of habitats and species	Number of protected bird species	Number of protected bird species (% of theoretically possible number of protected bird species)
				Species number of epigeic carabid beetles	Number of species per month (number per 30 days)
				Number of plant species	Number of plant species (% of theoretically possible number of species)
				Diversity of mammals	Number of species
		Pest and disease control	Control of pests and invasive species	Population density of ichneumon wasps	Number of ichneumon wasp individuals (number per hectare)
		Soil formation and quality maintenance	Decomposition and fixing processes	Thickness of the hydromorphic soil	m
		Water quality	Freshwater quality	Chemical and ecological quality of freshwater	Coefficient
		Atmospheric composition and climate regulation	Global climate regulation by reduction of greenhouse gas concentrations	Climate change mitigation	CO_2 eq./ha^{-1} year
			Microclimate regulation	Air temperature and evapotranspiration	Coefficient
				Potential for air quality mitigation	Coefficient
Cultural services	Recreation	Physical and empirical interactions	Use of plants, animals, landscape for recreation purpose, nature watching, education	Bird watching	Coefficient (infrastructure, bird diversity, access)
				Possibilities of active and passive recreation	Coefficient (access, infrastructure, nature diversity)
		Intellectual and representative interaction	Research and educational activities	Possibilities of environmental education	Coefficient (access, infrastructure, nature diversity)

Ecosystem services were evaluated in five LIFE REstore demo sites. In four demo sites, harvested peatlands were reclaimed allowing assessing each after-use scenario from the point of view of ecosystem services. In Ķemeri Mire, reintroduction of *Sphagnum* mosses and other raised bog plant species was carried out to promote development of peat-forming vegetation (rehabilitation) (see Chapter 6.3.3). In part of Kaigu Mire, trees were planted (see Chapter 6.3.1), whereas in another extracted peat field in the same area highbush blueberries *Vaccinium corymbosum* were planted (see Chapter 6.3.2). In Kaudzīšu Mire, a plantation of large cranberries *V. macrocarpon* was established (see Chapter 6.3.2). In Lauga Mire Nature Reserve, restoration of a degraded raised bog adjacent to peat extraction area was carried out by blocking the ditches (see Chapter 6.3.4).

Each of the abovementioned LIFE REstore demo sites is distinct. However, none of them was reclaimed after the completion of peat extraction, except for Ķemeri Mire where the cutaway peatland was rewetted in 2006, however, in the particular section the rehabilitation was not successful.

The actual values of ecosystem services in the Lauga Mire Nature Reserve were assessed over a specific period of time (one year). The ecosystem service assessment was initially carried out here, as there is a considerably larger variety of land cover types than in other LIFE REstore project demo sites. Also the classification of ecosystem services and relevant indicators were developed based on the assessment of Lauga Mire territory.

For each LIFE REstore demo site, both the ecosystem services for current, pre-reclamation situation were assessed, and evaluation of ecosystem services for five, 25- and 50-year development scenarios were carried out, assuming that:

- ✔ the condition of raised bog ecosystem in Lauga Mire will improve within 50 years, and its natural functions will recover;
- ✔ after reintroduction of *Sphagnum*, within 50 years peat-forming vegetation will develop in the former peat extraction area in Ķemeri Mire, and its natural ecosystem functions will recover;
- ✔ in tree plantations in Kaigu Mire, a forest will develop within 50 years; however, fast-growing poplars (*Populus* spp. v. *Vesten*) which were planted for energy use, could be harvested after 25 years;
- ✔ highbush blueberry plantations in Kaigu Mire will reach their maximum production within 8–10 years, and will continue to produce; plantation will be re-planted within 15–20 years, and will reach their maximum yield in the 25th year;
- ✔ large cranberry plantation in Kaigu Mire will start to provide regular cranberry harvest six years after planting; it is assumed that the plantation will provide a regular harvest during a 50-year period.

The ecosystem services provided by the current ecosystem condition reflect the values which could be expected if the reclamation would not be carried out. The evaluation of development scenarios using the approach of ecosystem services provides deeper insight into the benefits of a particular after-use scenario. Also the different periods of development scenarios allow evaluating the advantages of each scenario. For example, in the case of berry plantations, the yield and related benefits will be obtained much earlier than in the case of *Sphagnum* reintroduction (rehabilitation). However, when both areas (berry plantation and *Sphagnum* reintroduction area) are being evaluated over a longer period of time, the ratio of potential benefits changes.

In all LIFE REstore demo sites, except for Lauga Mire, the ecosystem services were evaluated also in the adjacent areas using them as reference condition (Figures 102–105). This allows in-depth understanding of the potential values of ecosystem services in territories in case of various development scenarios concerning land use change and provide reference condition. In Lauga Mire, the overall assessment for the entire nature reserve was carried out, because it was difficult to distinguish the reference area which would not be transformed by drainage and at the same time would be comparable to the demo site. Figure 102 shows the *Sphagnum* reintroduction demo site and adjacent areas in Ķemeri Mire, while Figure 103 shows the demo site and adjacent plantations of highbush blueberries in Kaigu Mire. Figure 105 shows Kaudzīšu Mire demo site and adjacent areas (large cranberry plantation).

Figure 102. *Sphagnum* reintroduction demo site in Ķemeri Mire. Map prepared by A. Rudusāne using the orthophotomap of 2013–2015, scale 1:10,000, © Latvian Geospatial Information Agency.

Figure 103. Afforestation demo site in Kaigu Mire. Map prepared by A. Rudusāne using the orthophotomap of 2013–2015, scale 1:10,000, © Latvian Geospatial Information Agency.

Figure 104. Highbush blueberry plantation demo site in Kaigu Mire. Map prepared by A. Rudusāne using the orthophotomap of 2013–2015, scale 1:10,000, © Latvian Geospatial Information Agency.

Figure 105. Large cranberry plantation demo site in Kaudzīši Mire. Map prepared by A. Rudusāne using the orthophotomap of 2013–2015, scale 1:10,000, © Latvian Geospatial Information Agency.

When evaluating the provisioning services provided by the demo sites before reclamation, the actual benefits were taken into account. For example, although volume of potentially extractable timber in the forests in Lauga Mire Nature Reserve varies in the range from 50 to 200 m^3 ha^{-1}, felling is not allowed in this protected nature area according to legislation, thus the use of this provisioning service is limited. Also mining, including peat extraction, is prohibited in nature reserves, therefore it is indicated in the ecosystem service assessment that the service is not actually provided.

Results and discussion

Ecosystem services provided by Lauga Mire Nature Reserve

In Lauga Mire Nature Reserve, the value of provisioning services was evaluated as low. In this group of ecosystem services, forests were the highest-valued habitat group, as they provide several services, such as wild berries, mushrooms and medicinal plants, game animals.

In the raised bog and degraded raised bog, provisioning services such as game animals and medicinal plants were very low rated.

The lowest value of provisioning services in Lauga Mire Nature Reserve was found in transition mires and quaking bogs, which occupy a small proportion of the area. The only provisioning service provided by transition mires and quaking bogs is medicinal plants (very low value).

Regulation and maintenance services in Lauga Mire were highly rated, which is in line with several other studies (Folley et al. 2005) which state that the highest value of undisturbed territories is their ability to provide the regulation functions of natural ecosystems. The most highly valued area, according its ability to provide regulation and maintenance services, is the active raised bog. It provides very high value ecosystem services such as the soil ability to accumulate nutrients, dilute pollution, provide erosion control, as well as to take in, accumulate and retain water.

Cultural services in the territory were valued on the basis of actually obtained benefits. The territory is located relatively far from densely populated areas, there is no special infrastructure for tourists (trails, signs, observation towers or platforms), and is not a popular destination. Consequently, its value of cultural services is of little importance.

It is evident that the highest value in Lauga Mire is provided by regulation and maintenance services. The reason of the high value of regulation and maintenance services may be that other services in the area are used to a small extent, and there is no significant interference in natural processes.

In order to get the most complete picture of the area, ecosystem services provided by the adjacent territories were also evaluated.

Ecosystem services provided by area adjacent to Lauga Mire Nature Reserve

There are various areas in the vicinity of Lauga Mire Nature Reserve, however, only the territories modified by economic activities were analysed within the LIFE REstore project. Figure 106 shows the territory of Lauga Mire Nature Reserve and the adjacent territories: peat extraction fields, large cranberry plantation, and abandoned cutaway peatland.

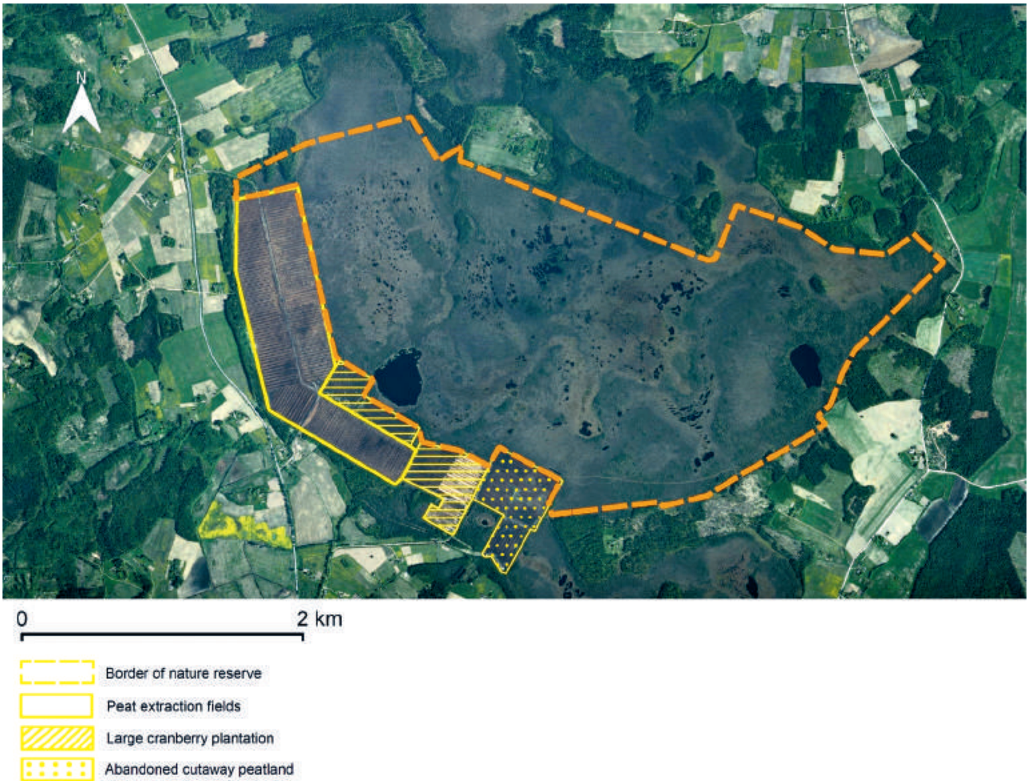

Figure 106. Lauga Mire Nature Reserve and adjacent areas included in the ecosystem service assessment. Map prepared by A. Priede using the orthophotomap of 2003–2008, scale 1:10,000, © Latvian Geospatial Information Agency.

When evaluating the provisioning services provided by the adjacent areas of Lauga Mire Nature Reserve, it was estimated that extraction of raised bog peat provides a high value. However, the territory does not actually provide any other provisioning services. In result, the total value of provisioning services for this area remains very low. The main value of provisioning services of large cranberry plantation is its ability to provide berry production. If comparing the regulation and maintenance services of peat extraction area, abandoned cutaway peatland and large cranberry plantation, the cranberry plantation gets the highest rating. It can ensure erosion control and maintenance of water cycling.

Abandoned cutaway peat field has the lowest value from the point of view of regulation and maintenance services. Its ability to maintain water cycling and microclimate regulation is very low. Soil erosion is characteristic to peat extraction sites. Sparse vegetation which could control erosion is found only in drainage ditches and on the edges of peat fields. Abandoned peat extraction fields do not provide any other ecosystem services.

Cultural services are not provided by any of the adjacent areas. In peat extraction fields and in the large cranberry field, access to unauthorized persons is prohibited. At the same time, at its current condition the abandoned cutaway peatland is not capable of providing recreational or intellectual interaction services.

Evaluation of ecosystem services in Lauga Mire Nature Reserve after five, 25 and 50 years

When assessing the future development scenarios of Lauga Mire Nature Reserve for five, 25 and 50 years, it can be concluded that only insignificant changes in the provided ecosystem services are expected. This territory has the status of a protected area, and economic activity here is not expected. Natural ecosystems and their services may improve due to ecosystem restoration (rewetting). However, the ecosystem recovery is not expected within a short period of time. Changes in land cover types are not expected during the next five and 25 years. Also no changes in the currently identified ecosystem services are expected.

After building of dams on drainage ditches as proposed in the nature protection plan of Lauga Mire Nature Reserve (Freimane (red.) 2017), it can be predicted that within 50 years the condition of degraded raised bog will improve, the functions of natural mire ecosystems will recover, also providing the relevant ecosystem services.

Evaluation of ecosystem services in demo sites before reclamation

In demo sites, after-use scenarios implemented by LIFE REstore project include planting of large cranberries (Kaudzīšu Mire), highbush blueberries (Kaigu Mire), afforestation (Kaigu Mire), and reintroduction of *Sphagnum*. All of these areas are former peat extraction sites. The entire accessible peat layer has been extracted, and peat extraction has been completed (in Kaudzīšu Mire and in Kaigu Mire) or discontinued and not resumed (Ķemeri Mire). Although these areas were different (various peat properties, peat extraction was completed or discontinued at different times), they were very similar in terms of ecosystem services.

Before implementation of after-use scenarios, these peat extraction sites did not provide almost any provisioning services. Medicinal plants were the only provisioning service. However, the value of this service is very low, as there are very few medicinal plant species in small quantity.

The value of regulation and maintenance services in these areas is also very low. Water accumulation capacity is the most highly rated regulation and maintenance service, though its value was rated low by the experts. Also the following services are valued as very low: nutrient accumulation; pollution control; erosion control; ensuring pollination and seed dispersal; habitats for species; control of pests and invasive species; microclimate regulation.

LIFE REstore demo sites have scientific and educational value. The scientific and educational services of demo sites are valued as very low, because no additional research was carried out before the implementation of after-use scenarios. The major scientific and educational value of these areas is related to establishment of demo sites. The knowledge on use of certain after-use scenarios is being improved through regular monitoring and research. The intrinsic scientific and recreational values of harvested peatlands are low. Also the outdoor education possibilities in peat extraction fields are low. Peat extraction sites provide scientific opportunities at low value; already before the implementation of the after-use scenarios, the territories were surveyed and monitored to evaluate the success of the implemented activities.

Ecosystem services provided by the adjacent areas

Evaluation of ecosystem services provided by the adjacent areas neighbouring to the demo sites is summarized in Table 22.

Table 22. Ecosystem services provided by the adjacent areas.

Territory Ecosystem service	Peat extraction fields	Degraded raised bog	Highbush blueberry plantation	Large cranberry plantation
Provisioning services	**High value of ecosystem service** – extraction of raised bog peat	**Very low value of ecosystem service** – game animals, medicinal plants	**Low value of ecosystem service** – highbush blueberries	**Medium value of ecosystem service** – large cranberries
Regulation and maintenance services	**Very low value of ecosystem service** – erosion control, maintenance, of water cycling, microclimate regulation	**Very low value of ecosystem service** – filtration and accumulation by ecosystems; pollination and seed dispersal; maintenance of habitats and species habitats (diversity of mammals); decomposition and fixation by soil. **Low value of ecosystem service** – mediation of noise, maintenance of habitats and species habitats (diversity of protected bird species). **Medium value of ecosystem service** – maintenance of water cycling; control of pests and invasive species. **High value of ecosystem service** – maintenance of habitats and species habitats (number of plant species and epigeic ground beetle species). **Very high value of ecosystem service** – erosion control.	**Very low value of ecosystem service** – filtration and accumulation processes in ecosystems; dilution of pollution; pollination and seed dispersal; control of pests and invasive species; microclimate regulation (regulation of air quality). **Low value of ecosystem service** – maintenance of habitats and species habitats (species number of epigeic ground beetles); microclimate regulation. **Medium value of ecosystem service** – decomposition and fixation by soil. High value of ecosystem service – erosion control; maintenance of water cycling.	
Cultural services	**Very low value of ecosystem service** – scientific and educational interaction	**Low value of ecosystem service** – use of plants, animals and landscape for recreation and nature watching; scientific and educational interactions.	Cultural ecosystem services are not provided.	

When examining the **provisioning** services provided by the adjacent areas neighbouring to the demo sites, the peat extraction fields in Kaigu Mire has the highest value. Here, raised bog peat is being extracted for horticultural use. Value of provisioning services provided by large cranberry plantation in Kaudzīšu Mire is evaluated as medium. Production of highbush blueberry plantation is valued as low as the berry plants have not yet reached the age of harvest maximum. Only the degraded bog in Ķemeri Mire (adjacent to demo site) can provide several provisioning services at the same time – there are plants that can be used in medicine (such as Labrador tea *Ledum palustre*, common heather *Calluna vulgaris*), and a small number of game animals. However, it is important to note that these services are very limited in the territory, which results in a very low evaluation of them.

The results of examining the **regulation** services of territories adjacent to LIFE REstore project demo sites can be seen in Table 22. The degraded raised bog can provide more regulation services than other areas, and their value is rated higher. Among them, erosion control is the highest-rated service. Soil covered with vegetation is significantly less affected by erosion than bare peat. Vegetation and litter serve as a physical barrier and prevent soil leaching caused by precipitation (Thornes 1985). In highbush blueberry and large cranberry plantations, service of erosion control is evaluated as high. In peat extraction site, this service is valued as very low.

Comparing the services provided by degraded raised bog and peat extraction fields, the amount of regulation services provided by the peat extraction fields is considerably smaller and their quality is very low. Only two regulation services are provided by peat extraction site: erosion control and capacity of peat to accumulate water.

Regulation services provided by both highbush blueberry and large cranberry plantations are identical. Berry plantations provide more regulation services than peat extraction fields, though less than degraded raised bog. Berry plantations provide such regulation services as erosion prevention and capacity of peat to accumulate water; both services are rated as high.

Evaluating the **cultural** services provided by the territories, it was found that in the active peat extraction site in Kaigu Mire, educational opportunities (excursions) are offered by SIA "Laflora". At the same time, the restored peatland in Ķemeri Mire in the surroundings of the demo site, provides several cultural services, such as bird watching, active and passive recreation, and environmental education. These cultural services and their quality are related to the available tourism infrastructure, easy access to the territory, and biodiversity.

Berry plantations do not provide cultural services because access to the territory is restricted.

Expected development of ecosystem services in after-use scenarios tested by LIFE REstore project: five, 25 and 50-year periods

Sphagnum reintroduction

By evaluating the possible development scenarios of ecosystem services in the Ķemeri Mire demo site, it was assumed that peat-forming vegetation will gradually develop after establishment of suitable water table and after reintroducing *Sphagnum* mosses and other raised bog plants. In the perspective of five years, it was assumed that *Sphagnum* will cover over 15% of the surface. Such cover is low, and therefore this provisioning service is evaluated as very low.

Sphagnum mosses were included in the evaluation of provisioning services, because in a case of successful *Sphagnum* establishment, it will be possible to use this area to acquire donor material for restoring other degraded bog areas, also in the neighbouring bare peat fields (Figure 102). However, this is not expected within the next five years, as also evidenced by the low rating of the indicator.

Together with *Sphagnum*, also other species of bog plants were planted, such as common cranberry *Oxycoccus palustris*; it is expected that wild berries will establish in the territory within five years; however, within the next five years, the value of this provisioning service will remain very low. It is expected that some medicinal plant species (e.g. common cranberry *Oxycoccus palustris*, common heather *Calluna vulgaris*) will establish in the demo site. However, also this ecosystem service is valued as low.

By analysing the regulation services provided by the territory, it is expected that the situation will improve if compared with the current rating. Within five years after rehabilitation, the territory will likely provide high-valued regulation services, such as pollution reduction (dilution) and erosion control. Most of the following regulation and maintenance services are rated as medium high: water accumulation capacity; maintenance of habitats and species; microclimate regulation; soil ability to accumulate nutrients. Ecosystem services which are rated as low within five years are: control of pests and invasive species and climate regulation by reduction of greenhouse gas emissions (GHG).

Regulation services rated as very low within the next five years are: noise mitigation and mammal diversity. The developed ecosystem service indicator classification scale for mammal diversity assumes that the value of the ecosystem service is very low in cases if the number of mammal species in the area is 0.1–20% of the potential species richness. It is expected that the food supply will improve after rehabilitation of the area, and wild animals from the adjacent areas will start to visit the area more frequently. Pollination and species dispersal are regulation services which are rated as very low; significant changes in their values are not expected.

The scientific and environmental education value may increase within five years after the rehabilitation. This type of *Sphagnum* planting for rehabilitation of extracted peatland is innovative in Latvia, therefore it is expected that the results and process will attract the interest of researchers, and the scientific value of the territory will increase.

Within 25 years, minor positive changes are expected. In the group of provisioning services, the highest value in comparison to the five-year development prognosis is expected for increase in biomass (assuming that *Sphagnum* will be successfully established and the cover of peat-forming vegetation will continuously increase).

Among regulation services, the growth of the value of the nutrient accumulation and water accumulation capacity services is expected. The most noticeable increase during the 25-year period (compared to the five-year development scenario) is the expected increase in mammal diversity. According to expert opinion, the value of this service will increase from very low to medium. It is assumed that, after reintroducing the *Sphagnum* and other bog plants in the harvested peatland, the raised bog vegetation will recover within 50 years, and it will attract animals from the adjacent areas. It is not expected that values of other regulation services will change (compared to the five-year development scenario).

In the group of cultural services, the addition of such ecosystem service as bird watching is expected in the 25-year perspective (territory will become suitable for mire birds because of the continuous vegetation cover). However, for this period this service is valued as very low.

In a **50-year perspective**, compared to 25-year development scenario, only minor changes are expected in the ecosystem services. No changes are expected in the group of provisioning services. In the group of regulation services, the increase in values is expected for following services: soil ability to adsorb and accumulate nutrients; water accumulation capacity; maintenance of habitats and species (related to diversity of mammal and plant species); microclimate regulation. The value of other regulation services will remain unchanged for five, 25, and 50-year periods.

In the group of cultural services, a positive change in bird watching possibilities is expected over the next 50 years. Compared to the 25-year development scenario, the value of this service will rise from very low to low. It is assumed that the value of this service will increase because the restored raised bog vegetation will become more attractive for bird breeding.

Afforestation

The tree plantation in Kaigu Mire will be able to provide more and more services over time, compared to the condition prior to reclamation. In the **five-year perspective**, the extracted peatland will change into a young tree stand.

It is expected that the territory will start to provide services such as wild berries and medical plants within the next five years, though the value of this service has been assessed as very low. Other provisioning services will not be provided by the territory.

Significantly higher value of ecosystem services will be provided in the group of regulation and maintenance services. It is expected that after five years there will be a young tree stand that will provide high-value regulation services such as pollution mitigation (dilution) and erosion control. Also the water accumulation capacity will improve. The initial assessment of this service was medium, but its value is expected to become high over a five-year period.

The value of cultural ecosystem services will increase over the next five years, mainly due to scientific and educational activities. It is expected that sufficient amount of data will be obtained over the five years, allowing drawing conclusions on the LIFE REstore project results. Also the public interest on similar reclamation measures might rise, and the number of interested scientists and industry stakeholders might increase. However, it should be noted that the value of the environmental education service will remain unchanged over a period of five, 25 and 50 years, anticipating that the interest of researchers on the demo site will not increase significantly.

Within 25 years, the values of ecosystem services of afforested area in all service groups will rise. The most significant increase is expected in provisioning services, because the fast-growing poplars will reach timber volume which is suitable for felling.

Regulation services were rated as almost identical, when 25-year and five-year development scenarios were compared. Differences were found only in ecosystem service classes such as (1) noise reduction (its value will increase, and will be valued as very high after 25 years), and (2) climate regulation by reducing GHG emissions (the value of this service will increase, and will be evaluated as high after 25 years). The territory will have a scientific and educational significance, and the values of cultural services will be the same as those of five years.

In the **50-year perspective**, the value of Kaigu Mire tree plantations will continue to grow in terms of ecosystem services. In the group of provisioning services, obtainable timber volumes for materials and obtainable tree biomass for energy use are maximally high rated.

In the group of regulation services, the only ecosystem service indicator that changes over 50 years compared to the 25-year period, is global climate regulation by reducing GHG emissions. The value of this service is expected to reach its maximum value in 50 years. For 25 to 50-year-old trees of target species (silver birch *Betula pendula*, common alder *Alnus glutinosa*, Scots pine *Pinus sylvestris*), growth increments will reach the maximum, and consequently the GHG emission reduction will be significantly higher than in the first 25 years after afforestation.

The values of cultural services are expected to be the same as in the 25-year perspective, assuming that research and environmental education activities will be continued in the territory.

Highbush blueberry plantation

When evaluating the development of the territory within five, 25 and 50 years, it was concluded that the value of ecosystem services in all the mentioned periods will be almost identical. Five years later, berry bushes will be established and will produce the expected harvest.

From the perspective of provisioning services provided by highbush blueberry plantation within five years, even if the area would be able to provide harvest, its volume would be low. Highbush blueberries reach their maximum production from the eighth to the tenth year. Therefore, the growth of provisioning services value is expected for a period between 25 and 50 years. It is assumed that if the assessment of ecosystem services would be carried out from the eighth to the tenth year, the provisioning service – the berry production – would probably be rated as very high.

It is expected that values of ecosystem services in highbush blueberry plantations after 25 years will not differ significantly from the situation after 50 years. Considering that the productivity of blueberries reaches its peak from the eighth to the tenth year, but then the production gradually decreases, new plants are planted after 25 years in order to get the highest possible yield. Thus, after 50 years, berry bushes will reach the same age and also the same productivity as after 25 years.

Also regulation and maintenance services for highbush blueberry plantations in the **fifth, twenty-fifth and fiftieth** year will be identical and no changes are expected. The most highly rated regulation and maintenance services in the area are: erosion control and maintenance of water cycling. Services such as pollution reduction (dilution), maintenance of habitats and species, soil formation and soil quality maintenance, microclimate regulation (indicator – air temperature and evaporation), are evaluated as low. All the values of mentioned ecosystem service classes will be higher if compared with the situation before the establishment of plantations.

The following classes of regulation services remain unchanged (if compared with harvested peatland without reclamation): soil ability to adsorb and accumulate nutrients; pollination and seed dispersal; control of pests and invasive species.

Also the cultural services provided by highbush blueberry plantations will be in the same level after five, 25 and 50 years. The only cultural ecosystem service that the area will provide is the scientific and educational activity. It is expected that within five years the results of the LIFE REstore project will be analysed and the territory could be used as a demonstration area of this after-use scenario.

Large cranberry plantation

Ecosystem services provided by large cranberry field over five, 25 and 50 years can be analysed together because no changes are expected over these years. Large cranberries start to produce berry yield in the third year and continues for 50–100 years. Consequently, there are **no significant differences among development scenarios for five, 25 and 50 years**.

In the group of provisioning services, it is expected that large cranberries will be the main production of the plantation. At the same time, there will be also medicinal plants available, such as common heather, though their value will be very low.

Regarding the regulation services, it is expected that the large cranberry plantation established in the LIFE REstore demo site will provide similar regulation services as large cranberry plantation which is located near the demo site (results of analysis presented above).

The values of cultural services are assumed the same as for extracted peatland – the value of scientific and educational activities is very low. The cultivation of large cranberries in harvested peatland is not a novelty in Latvia. Therefore, also the scientific contribution of this economic activity is insignificant.

Conclusions

From the perspective of ecosystem services, before implementing after-use scenarios in LIFE REstore demo sites, the value of these areas was low. The highly degraded, harvested peatlands produced high carbon dioxide (CO_2) emissions, contributing to climate change. In addition, these emissions would remain high as long as the peat extraction site remains would not be reclaimed i.e. converted into other land use type.

Medicinal plants are the only provisioning service that can be provided by harvested peatlands, but the value of this service is very low. To some extent, these areas were able to provide regulation services and cultural services. However, already five years after reclamation, positive changes in terms of ecosystem services are expected in all LIFE REstore demo sites. The greatest positive changes are expected in the group of regulation services.

Within five and 25 years, the most valuable ecosystem services will be provided by afforested area, as it provides high regulation services and, at the same time (compared with other after-use scenarios in LIFE REstore demo sites), also high-level provisioning services. Afforestation is also seen as the most effective after-use scenario for global climate change mitigation.

Within 50 years, high value ecosystem services are expected both in afforestation and *Sphagnum* reintroduction areas. Comparing these two areas, tree plantations provide the highest value of provisioning services – ensuring biomass and timber volumes. From the point of view of the regulation services, *Sphagnum* reintroduction area with expected peat-forming vegetation is more valuable.

When evaluating the plantations of highbush blueberries and large cranberries, it was concluded that these territories will provide equally high ecosystem services in the five, 25, and 50-year periods.

The value of cultural services provided by the demo sites is rated as low, however, scientific and educational contribution due to experimental and scientific value would be provided by all after-use scenarios.

Lauga Mire Nature Reserve is the only demo site where peat has not been extracted. This site provides diverse regulation services with high values. The most valuable ecosystem services are provided by active raised bog. By modelling the development of the territory during five, 25 and 50 years, and assuming that in the next 50 years the peatland damaged by peat extraction will recover and function as intact bog, the value of Lauga Mire ecosystem services will increase. The value of cultural services in Lauga Mire is low, and significant growth of this service is expected, because the territory is rather far from densely populated areas and there is no infrastructure for tourism and other activities related to cultural services.

5.2. Economic value of peatland ecosystem services

Aija Peršēvica, Agnese Jeņina

Summary

Expressing ecosystem services in economic values is a practicable approach which can be used, for example, in nature conservation and management, where difficult decisions have to be made, to find compromise between the interests of economy and nature conservation. The economic evaluation of ecosystem services provides assistance for decision making and prioritizing different, sometimes conflicting, development plans.

In LIFE REstore project, the economic assessment of ecosystem services has been carried out for little affected peatland (Lauga Mire Nature Reserve), for a peat extraction area, and for a cutaway peatland. Based on the expert evaluation of ecosystem services, an economic assessment of ecosystem services was carried out for several after-use scenarios in the project for a period of five, 25 and 50 years.

The highest economic value of ecosystem services was found for regulation services of natural and slightly disturbed peatlands. If the area is used for peat extraction, it provides provisioning services of high economic value. However, after completion of peat extraction, the value of territory becomes relatively low, providing only low-volume regulation services.

Comparing the reclamation measures in areas affected by peat extraction implemented in project demo sites, the highest values of provisioning services were found for highbush blueberry plantations. The highest values of regulation services were found for afforested area.

Introduction

Ecosystem services are crucial to the existence of humans, but the assessment of their economic importance is difficult. Moreover, ecosystem services that are not directly used in the market are disproportionately neglected at the time of making a decision. Thus, when taking decisions, preference could be given to services and decisions with generally accepted commercial value. From an economic point of view, the use of some ecosystem services is favourable in the short term, but it can be a threat to the environment and society if risks are recognized and long-term impacts are assessed. Peat extraction is a striking example. This natural resource can generate fast and relatively high profit, which is important for entrepreneurs. However, ecosystem regulation services are substantially affected by the transformation of natural environment. Consequently, the economic value of ecosystem services can be decisive in making sustainable decisions, ensuring a balanced approach between the ecosystem potential and the socio-economic development of society.

Determining the monetary value of ecosystem services is a good way of communicating with representatives from various sectors. First, it allows comparing different values in unified (monetary) terms. Second, values of ecosystem services are presented in units which are most understandable for the community (in the case of LIFE REstore project – euro).

In the decision-making process, on the basis of economic assessment of ecosystem services, it is possible:

- ✔ To assess the impact of the economic development of certain territories (for example, extraction of mineral resources and peat) on ecosystem services and thus on the well-being of people;
- ✔ To analyse cost-effectiveness of planned activities or investments;
- ✔ To assess alternatives of various environmental management scenarios, and choices between various land use purposes;
- ✔ To identify the cost of environmental damage;
- ✔ To create a market of ecosystem services in order to mobilize financial resources; for example, for energy production and payments for ecosystem services;
- ✔ To raise public awareness on the overall contribution of ecosystem services to social and economic well-being (GIZ 2012).

There are several advantages for expressing ecosystem services in economic values. For example, in order to ensure nature conservation and management, difficult decisions must often be made to find a compromise between the interests of business and biodiversity conservation. The economic assessment of ecosystems and their services is also necessary in order to estimate the human impact on ecosystems, based on ecosystem services and their value. Indirect values of ecosystem services expressed in monetary terms are more readily perceived by community. The results of the assessment help in decision making when two or more development scenarios have to be compared. If the values are expressed in monetary terms, they are more comparable.

Material and methods

Calculation of economic value of ecosystem services is necessary for the monetary accounting of nature resources and ecosystem services, as well as for the evaluation of benefits and losses. The results allow us to assess the benefits and losses of various development scenarios in monetary terms related to changes in land use or management. For example, such evaluation allows assessing the value of raised bog not only as a peat resource but also as an ecosystem which ensures various other services – air purification, pollution reduction, recreation opportunities.

Usually, it is easier to account the direct-use values (for example, the economic value of food resources) as they are sold on the free market. Identification of economic values of ecosystem services that are not bought and sold is much more difficult. However, these services are essential to the existence of society. These services are the hardest to quantify and have the greatest uncertainty.

Methods of economic evaluation of ecosystem services

Various valuation methods are used to determine the monetary values of ecosystem services:

- ✔ *Direct market pricing* – calculates the monetary value that is determined and paid for goods and services traded on the market;
- ✔ *Production function method* – calculates the economic values for goods or services of ecosystem that promote the production of commercial goods;
- ✔ *Avoided cost method* – monetary values are calculated on the basis of cost of avoided damage.
- ✔ *Replacement cost method* – costs for ecosystem replacement services;
- ✔ *Contingent valuation (constructed market) method* – service value is estimated with a hypothetical scenario based on an assessment of alternative land uses (for example, people's

willingness to pay for conservation of coastal habitats and beach instead of building up).

- ✔ *Travel cost method* – the "price" of a particular site is obtained by summing up the time and money people spend in visiting a particular location;
- ✔ *Hedonic pricing method* – evaluates the economic value of ecosystems or environmental services that directly affect market prices. This method is most often applied to changes in real estate prices that reflect the value of the local environment;
- ✔ *Benefit transfer method* – used to assess the economic value of ecosystem services by transferring available information from other research studies which have been carried out at a different location and/or context;
- ✔ Other methods, as well as a combination of methods.

The choice of ecosystem service economic valuation method usually depends on the type of service, the availability of research information and time resources, and the purpose of the study. For example, if the purpose of economic evaluation of cultural services is to understand how many people are visiting the site and the time they spend there, the most appropriate method would be a travel cost method. If the aim is to find out whether people would be willing to pay for establishment of visitor infrastructure in the territory, then contingent valuation would be a more suitable method.

Depending on the category of ecosystem services, the following evaluation methods are most commonly used:

- ✔ For provisioning services – market price method and productivity method;
- ✔ For regulation services – cost elimination method, benefit transfer method and replacement cost method;
- ✔ For cultural services – market price method, benefit transfer method, contingent valuation (constructed market) method and travel cost method.

In LIFE REstore project, the following methods were used: (1) market price method for valuation of provisioning and regulation services; (2) benefit transfer method for valuation of regulation and cultural services; (3) replacement cost method for valuation of provisioning and regulation services; (4) cost elimination method for valuation of regulation services.

For the evaluation of ecosystem services, secondary data analysis was mainly used. In secondary data analysis, data from previous studies and available information are used, without the collection for new quantitative data. For the economic assessment of ecosystems, the database TEEB (*The Economics of Ecosystems and Biodiversity*), *Ecosystem Service Validation Database* (ESVD) (McVittie, Hussain 2013) and other statistics or similar data sources were used.

The economic evaluation of ecosystem services of project demo sites was carried out within the framework of the project to determine monetary values of several after-use scenarios: establishment of highbush blueberry and large cranberry plantations, afforestation, *Sphagnum* reintroduction. The value of ecosystem services was also calculated for an active peat extraction site and for a cutaway peatland. In order to identify the possible future changes in value, economic values of ecosystem services were calculated for development scenarios over five, 25 and 50 years.

For each territory and geospatial unit, monetary value was calculated in standardized units: total area/geospatial unit (EUR x ha), and standardized unit of space and time (EUR/ha/year).

A very important precondition for the determination of the economic value of ecosystem services was the expert assessment (see Chapter 5.1), which included also the development of indicators of ecosystem assessment. In the process of indicator development, experts not only described the evaluation of a particular ecosystem service, but also set parameters that were later used in economic assessment of ecosystem services.

An example of monetary valuation of ecosystem service

The economic assessment for **ecosystem service "pest and invasive species control"** was carried out using the indicator developed by expert V. Spuņģis. For limitation of pests and invasive species, **population density of ichneumon wasps** was used. Number of ichneumon wasp individuals per hectare was obtained using a standardized insect net and a defined method.

Ichneumon wasps are parasitoids (parasitoid – an organism that lives in close association with its host and at the host's expense, and sooner or later kills it). Their diversity is huge, ranging from microscopic egg parasitoids (*Trichogramma* spp.), parasitoids of small insect larvae (*Halicidae*, aphis parasite wasps and several related groups) to large sized parasitoids, predominantly ichneumon wasps. Ichneumon wasps are the most important parasitoids of butterflies and beetles, and they can effectively limit their population size. Ichneumon wasps limit the spread of various pests; the higher their number, the better the pest protection.

In order to determine the economic value of ecosystem services, the replacement cost method was used, considering the market price of the insecticide *Actara*, which is a broad-spectrum insecticide. A 250 g package is available on the market for EUR 65, and one kilogram would cost EUR 260/kg. The doses given in the instructions differ for various pests and vary from 0.1 to 0.2 kg/ha for particular crops. It was assumed that the necessary dose is 0.1 kg/ha.

The following algorithm was used for the determination of monetary value:

Geospatial unit area x percentage of correction x required quantity (0.1 kg/ha) x price 260 EUR/kg (Ardenis 2018).

More about the economic assessment of ecosystem services: https://restore.daba.gov.lv/public/lat/aktivitates_un_rezultati/purvu_ilgtspejigas_izmati_optimimas_modela_izstrade_ii_karta_ekosystems_services_economy_process_is_index_terms/.

Results and discussion

The results of the evaluation allowed comparing the economic values of ecosystem services of raised bog, active peat extraction site and extracted peatland (Figure 107). Benefits provided by these differing areas are various – different benefits are provided by natural or slightly disturbed mire, by peat extraction, and after the completion of peat extraction.

The greatest contribution of natural or slightly disturbed mire is its ability to ensure economically highly valuable regulation services. At the same time, the value of provisioning services is very low. On the contrary, the most important contribution of active peat extraction site is its ability to provide supply services with very high economic value.

After the cessation or completion of peat extraction, the economic value of ecosystem services is the lowest compared to active peat extraction site or intact peatland. The territory is no longer able to provide provisioning services. The economic value of regulation services is very low compared to natural or slightly disturbed mires.

When comparing the ability to provide cultural services for intact (undisturbed) or slightly disturbed mire, active peat extraction site and extracted peatland, the economic value of raised bog area is the highest. The primary objective of active peat extraction site is the extraction of natural resources, but the site does not provide recreational and cultural services. An extracted peatland is not attractive for visitors, therefore its economic value is low.

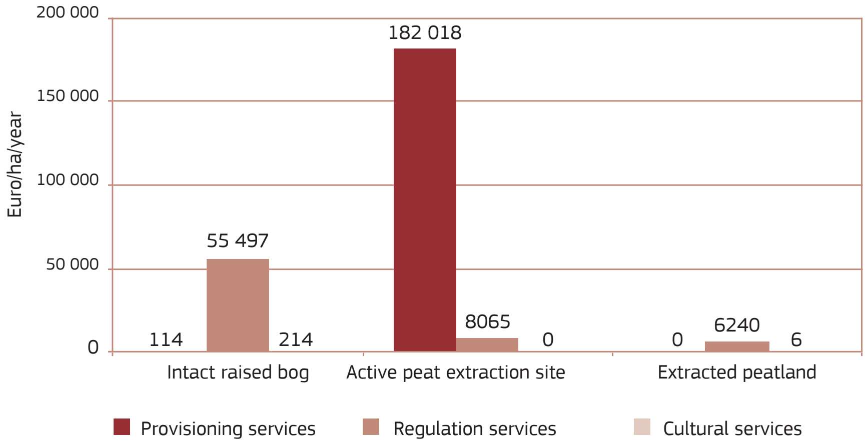

Figure 107. Economic values of ecosystem services of raised bog, active peat extraction site and extracted peatland.

The estimated economic values of ecosystem services impressively illustrate the losses that occur when extracted peatlands are not reclaimed.

Economic value of provisioning services of after-use scenarios implemented by LIFE REstore

The economic values (EUR/ha) of **provisioning services** for all project demo sites over five, 25 and 50 years are shown in Figure 108. In five years, the value of provisioning services will be similar for almost all demo sites. The highest monetary value of ecosystem services over a five-year period is estimated for large cranberry plantation as regular harvest of large cranberries is expected starting from the fifth year, with an average of 14-40 t (maximum 56 t) of berries per hectare (Silava 2016).

The lowest value of provisioning services over a five-year period is expected for afforested area because wood is not yet harvested in such a short time. At the same time, wild berries and herbs are available in small amounts, creating provisioning services of small economic value.

The relatively high economic value of provisioning services of *Sphagnum* moss reintroduction over a five-year period is provided of the availability of wild berries, medicinal plants and *Sphagnum* as donor material.

In 25-year period, the highest benefits of provisioning services are provided by highbush blueberry plantation, and this value remains high even in 50-year period. The consistently high economic value of provisioning services of this territory is explained by fact that the productivity of highbush blueberries is the highest in 25 years, after which berry bushes are replaced by new ones, and after the next 25 years (in 50 years), bushes reach the same productivity as in the 25th year.

The value of provisioning services for *Sphagnum* reintroduction site in a 25-year period is also increasing. The area provides the same range of services as in the five-year period, but over a period of 25 years, these services are provided to a greater extent than earlier, and these services are provided in an equivalent amount for the next 50 years.

The economic value of provisioning services of large cranberry plantation is the same in five, 25 and 50-year periods, as large cranberries can be grown in the same place for 50–100 years with similar yields (Silava 2016).

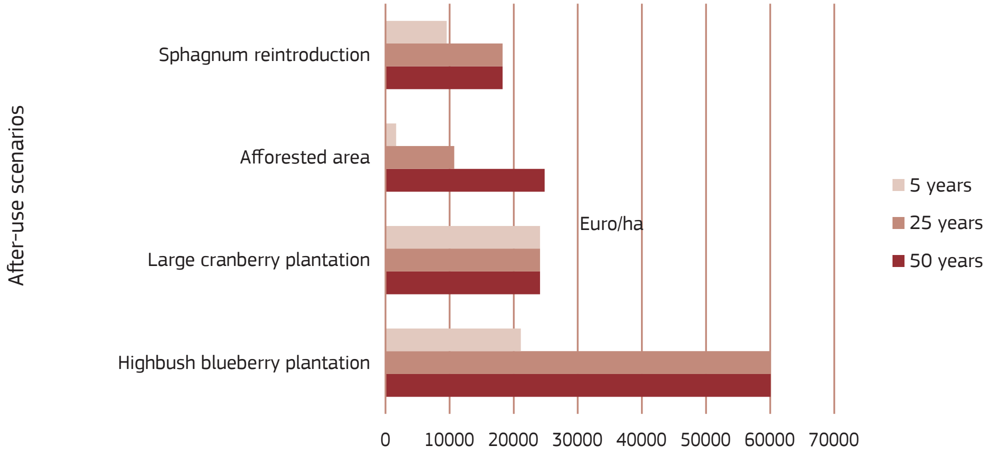

Figure 108. The economic values of provisioning services of after-use scenarios tested within LIFE REstore project.

The value of afforested land provisioning services is gradually increasing in both the 25-year and 50-year periods. This is explained by the growth rate of various planted tree species and the possibility to use fast-growing species (poplars) already 25 years after the planting.

Economic value of regulation services of after-use scenarios implemented by project

When evaluating the **regulation services** provided by the project demo sites (Figure 109), it can be concluded that changes in monetary values over the five, 25 and 50-year periods are small. For example, the economic value of regulation services of large cranberry plantation remains almost unchanged in the five, 25 and 50-year periods.

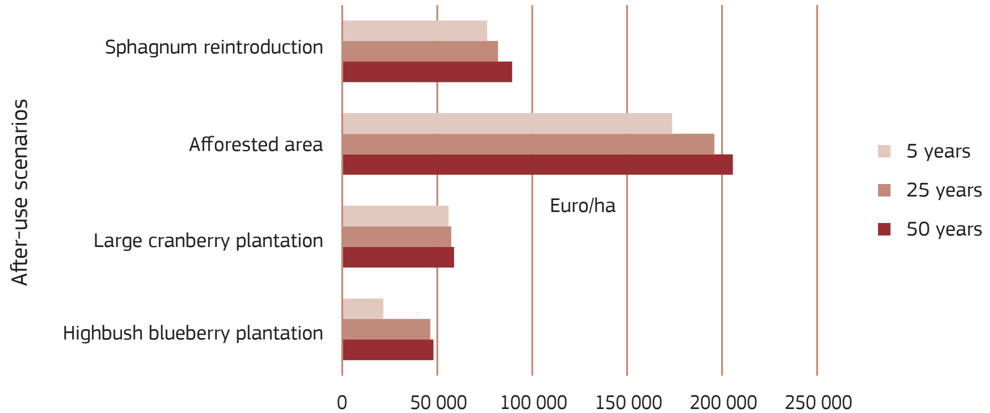

Figure 109. Economic values of regulation services of after-use scenarios tested within LIFE REstore project.

The afforested area has the highest economic value of regulation services, and high economic value of regulation services is expected already in the fifth year. Despite the fact that trees are purposefully planted and the purpose of planting is to produce energy wood, the area can be considered as a forest, ecosystem services of which are highly valued. The highest economic values of regulation services in tree plantation are: mediation of noise, erosion prevention, maintenance of habitats and species habitats.

The monetary value of regulation services in highbush blueberry plantation does not change in the periods of 25 and 50 years. Although the economic values of regulation services provided by highbush blueberry plantation are the lowest in comparison with other after-use scenarios, the largest changes in monetary values of regulation services are expected. If five and 25-year periods are compared, the monetary value of regulation services doubles.

Economic value of cultural services of after-use scenarios implemented within the project

The economic values of **cultural services** in project demo sites (Figure 110) are significantly below the values of provisioning and regulation services. Moreover, the monetary values of cultural services remain unchanged over 50 years in almost all demo sites. The only area where the economic value of cultural services is increasing over time is the area of renaturalization (*Sphagnum* reintroduction). Here, the increase in economic value of services is explained by the increase in the range of cultural services available.

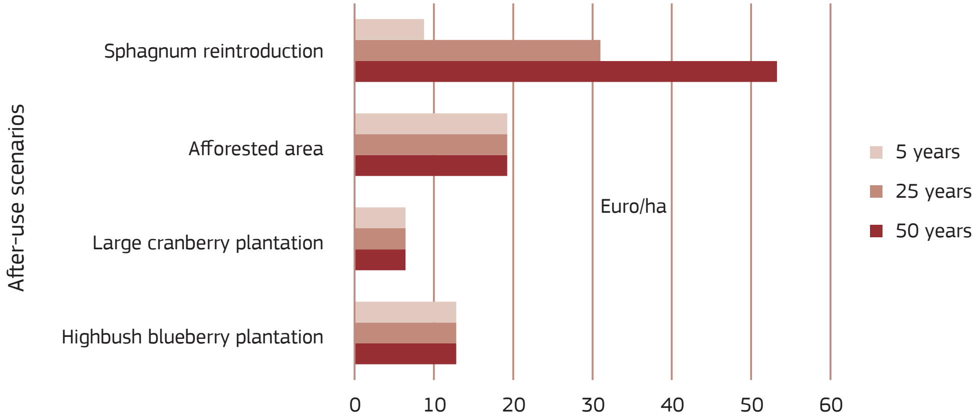

Figure 110. Economic values of cultural services of after-use scenarios tested within LIFE REstore project.

Conclusions

When comparing the ecosystem services of natural areas and peat extraction sites, the economic value of active peat extraction site is substantially higher. However, it is important to evaluate the long-term changes in ecosystem services – also after the completion of peat extraction. If comparing the economic value of active peat extraction site and natural or slightly disturbed raised bog ecosystem services within a period of one year, the economic value of peat extraction ecosystem services is higher than in natural mire. However, peat can be harvested in a relatively short time, whereas it recovers very slowly. Therefore, when comparing the peat extraction site and the natural or slightly disturbed raised bog over a longer period of time, for example, over a five-year period, the economic value of natural bog ecosystem services is higher. When the extraction of peat is completed and if reclamation is not carried out, the ecosystem services provided by site are significantly reduced, and due to the degraded condition, ecosystem services remain low for a long time.

Comparing the monetary value of the project's demo sites, the highest value in both the 25 and 50 years is for the area of highbush blueberry plantation.

When evaluating the regulation services of implemented after-use scenarios, it can be concluded that afforestation is characterized by a significantly higher value than other after-use scenarios for all the evaluated time periods.

In the five-year period, afforested area is characterized by the highest value of cultural services. However, only in the *Sphagnum* reintroduction area the values of these services continue to grow over the years.

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Annex 3. Indicator data sheet

Category of ecosystem service	
Class of ecosystem service	
Indicator	
Definition of indicator	
Unit of measure	
Author of data sheet	

Data and assumptions used for the development of indicator

Table 1. Raw data for the classification of ecosystem services

Table 2. Indicator scale classification of ecosystem services (ES) assessment

ES assessment	Indicator
0 – ES not provided	
1 – ES very low value	
2 – ES low value	
3 – ES medium value	
4 – ES high value	
5 – ES very high value	

Table 3. ES evaluation matrix

Code	Geospatial unit	ES assessment according to indicator scale of Table 2
1.	**Mire**	
1.1.	Raised bog	
1.2.	Degraded raised bog	
1.3.	Transition mire	
2.	**Forests**	
2.1.	Bog woodland	
2.2.	Western Taiga	
3.	**Freshwater habitats**	
3.1.	Natural watercourses	
3.2.	Ditches	
3.3.	Lakes or bog pools	
4.	**Economic activity**	
4.1.	Peat extraction site	
4.2.	Large cranberry plantation	
4.3.	Harvested peatland	

No.	Data source

Annex 4. Matrix-assessment of ecosystem services in LIFE REstore demo sites

Matrix-assessment of ecosystem services in demo sites

Category	Division	Group	Class	Indicator	Measurement units	Cutaway peatland in Kaigu Mire				
Three main categories of ecosystem services	Product of ecosystem services	Division of ecosystem services products (Biological, physical or cultural type of processes)	Biological or material outputs, and biophysical or cultural processes which can be related to particular service	Indicators		Highbush blueberry plantation				
						Current situation		SCENARIO: Highbush blueberry cultivation		
						Highbush blueberry plantation	Harvested peatlands	5 years: Highbush blueberry plantation	25 years: Highbush blueberry plantation	50 years: Highbush blueberry plantation
Provisioning services	Nutrition	Biomass	Cultivated crops	Crops of large cranberries/highbush blueberries	t/ha year	2	0	2	3	3
			Wild plants, mushrooms and their outputs	Crops of wild berries	t/ha year	0	0	0	0	0
			Wild animals	Game	number/ha	0	0	0	0	0
			Animals from *in-situ* aquaculture	Amount of fish	kg/ha year	0	0	0	0	0
	Materials	Biomass	Fibre and other materials from plants, algae and animals, for direct use or for processing (wood, *Sphagnum*, furs)	Volume of timber	m3/ha/year	0	0	0	0	0
				Sphagnum mosses	Cover (%)	0	0	0	0	0
				Peat for horticulture	Thickness (m)	0	0	0	0	0
				Tumšā kūdra	Kūdras biezums metros	0	0	0	0	0
				Limonīts, purva dzelzs rūda	t	0	0	0	0	0
				Amount of collected medical plants	Number of species	0	0	1	1	1
		Water	Water for agricultural use	Water for growing of large cranberries/highbush blueberries	m3/ha/year	0	0	0	0	0
	Energy	Biomass-based energy sources	Plant-based resources	Wood biomass for energy production	m3/ha/year	0	0	0	0	0
Regulation and maintenance	Mediation of pollution, toxics and other nuisances	Processes in ecosystems	Storage and accumulation in ecosystems	Soil ability to bind and accumulate nutrients	Coefficient	1	1	1	1	1
			Dilution of pollution	Amount of pollutants and aerosols diluted by ecosystem	Coefficient	1	1	2	2	2
			Mediation of noise	Woodland density	Index	0	0	0	0	0
	Mediation of flows	Mass flows	Erosion control	Vegetation cover providing the erosion protection	Vegetation cover, %	4	1	4	4	4
		Liquid flows	Maintenance of water cycling	Sediment water capacity and water storage capacity	Complex parameter	4	2	4	4	4
	Maintenance of physical, chemical, biological conditions	Lifecycle maintenance, habitat and gene pool protection	Pollination and seed dispersal	Biodiversity and abundance of insect pollinators	Number of species and individuals per hectare	1	1	1	1	1
			Maintenance of habitats and species	Number of protected bird species	Number of protected bird species (% of theoretically possible number of protected bird species)	0	0	0	0	0
				Species number of epigeic carabid beetles	Number of species per month (number per 30 days)	2	1	2	2	2
				Number of plant species	Number of plant species (% of theoretically possible number of species)	0	0	0	0	0
				Diversity of mammals	Number of species	0	0	0	0	0
		Pest and disease control	Control of pests and invasive species	Population density of ichneumon wasps	Number of ichneumon wasp individuals (number per hectare)	1	1	1	1	1
		Soil formation and quality maintenance	Decomposition and fixing processes in soil	Thickness of hydromorphic soil	m	3	1	2	2	2
		Water quality	Freshwater quality	Chemical and ecological quality of freshwaters	Coefficient	0	0	0	0	0
		Atmospheric composition and climate regulation	Global climate regulation by reduction of greenhouse gas concentration	Climate change mitigation	CO2 eq/ha-1 year	0	0	0	0	0
			Microclimate regulation	Air temperature and evaporation	Coefficient	2	0	2	2	2
				Potential for air quality mitigation	Coefficient	1	0	1	1	1
Cultural services	Recreation	Physical and empirical interactions	Use of plants, animals, landscape for recreation purpose, nature watching, education	Bird watching	Coefficient	0	0	0	0	0
				Possibilities of active and passive recreation	Coefficient	0	0	0	0	0
		Intellectual and representative interaction	Scientific and educational activities	Possibilities of environmental education	Coefficient	0	1	2	2	2

Indicator	Cutaway peatland in Kaigu Mire					Cutaway peatland in Ķemeri Mire				
	Afforestation					*Sphagnum* reintroduction				
	Current situation		SCENARIO: Afforestation			Current situation		SCENARIO: Raised bog		
	Peat extraction fields	Harvested peatlands	5 years: Bog woodland	25 years: Bog woodland	50 years: Bog woodland	Degraded raised bog	Harvested peatland	5 years: Raised bog	25 years: Raised bog	50 years: Raised bog
Crops of large cranberries/highbush blueberries	0	0	0	0	0	0	0	0	0	0
Crops of wild berries	0	0	1	1	1	0	0	1	1	1
Game	0	0	0	0	0	1	0	0	0	0
Amount of fish	0	0	0	0	0	0	0	0	0	0
Volume of timber	0	0	0	3	5	0	0	0	0	0
Sphagnum mosses	0	0	0	0	0	0	0	1	2	2
Peat for horticulture	4	0	0	0	0	0	0	0	0	0
Tumšā kūdra	0	0	0	0	0	0	0	0	0	0
Limonīts, purva dzelzs rūda	0	0	0	0	0	0	0	0	0	0
Amount of collected medical plants	0	0	1	1	1	1	1	2	2	2
Water for growing of large cranberries/highbush blueberries	0	0	0	0	0	0	0	0	0	0
Wood biomass for energy production	0	0	0	3	5	0	0	0	0	0
Soil ability to bind and accumulate nutrients	0	1	3	3	3	1	1	3	4	5
Amount of pollutants and aerosols diluted by ecosystem	0	1	5	5	5	0	1	5	5	5
Woodland density	0	0	3	5	5	2	0	1	1	1
Vegetation cover providing the erosion protection	1	1	5	5	5	5	1	5	5	5
Sediment water capacity and water storage capacity	1	2	4	4	4	3	2	3	4	5
Biodiversity and abundance of insect pollinators	0	1	2	2	2	1	1	1	1	1
Number of protected bird species	0	0	3	3	3	2	0	3	3	3
Species number of epigeic carabid beetles	0	1	3	3	3	4	1	3	3	3
Number of plant species	0	0	3	3	3	4	0	3	3	4
Diversity of mammals	0	0	1	1	1	1	0	1	3	4
Population density of ichneumon wasps	0	1	2	2	2	3	1	2	2	2
Thickness of hydromorphic soil	0	1	3	3	3	1	1	3	3	3
Chemical and ecological quality of freshwaters	0	0	0	0	0	0	0	0	0	0
Climate change mitigation	0	0	3	4	5	0	0	2	2	2
Air temperature and evaporation	1	1	3	3	3	2	1	3	3	4
Potential for air quality mitigation	0	0	3	3	3	3	0	3	3	4
Bird watching	0	0	0	0	0	2	0	0	1	2
Possibilities of active and passive recreation	0	0	0	0	0	2	0	0	0	0
Possibilities of environmental education	1	1	3	3	3	2	1	3	3	3

Indicator	Cutaway peatland in Kaigu Mire				
	Large cranberry plantation				
	Current situation		SCENARIO: Large cranberry cultivation		
	Large cranberry plantation	Harvested peatland	5 years: Large cranberry plantation	25 years: Large cranberry plantation	50 years: Large cranberry plantation
Crops of large cranberries/highbush blueberries	2	0	3	3	3
Crops of wild berries	0	0	0	0	0
Game	0	0	0	0	0
Amount of fish	0	0	0	0	0
Volume of timber	0	0	0	0	0
Sphagnum mosses	0	0	0	0	0
Peat for horticulture	0	0	0	0	0
Tumšā kūdra	0	0	0	0	0
Limonīts, purva dzelzs rūda	0	0	0	0	0
Amount of collected medical plants	0	0	1	1	1
Water for growing of large cranberries/highbush blueberries	0	0	0	0	0
Wood biomass for energy production	0	0	0	0	0
Soil ability to bind and accumulate nutrients	1	1	1	1	1
Amount of pollutants and aerosols diluted by ecosystem	1	1	2	2	2
Woodland density	0	0	0	0	0
Vegetation cover providing the erosion protection	4	1	5	5	5
Sediment water capacity and water storage capacity	4	2	4	4	4
Biodiversity and abundance of insect pollinators	1	1	1	1	1
Number of protected bird species	0	0	0	0	0
Species number of epigeic carabid beetles	2	1	2	2	2
Number of plant species	0	0	0	0	0
Diversity of mammals	0	0	0	0	0
Population density of ichneumon wasps	1	1	1	1	1
Thickness of hydromorphic soil	3	1	3	3	3
Chemical and ecological quality of freshwaters	0	0	0	0	0
Climate change mitigation	0	0	0	0	0
Air temperature and evaporation	2	1	2	2	2
Potential for air quality mitigation	1	0	1	1	1
Bird watching	0	0	0	0	0
Possibilities of active and passive recreation	0	0	0	0	0
Possibilities of environmental education	0	1	1	1	1

Indicator	Lauga Mire Nature Reserve (current situation and after 5 years)										
	Rewetting										
	Mires			Forests		Freshwater habitats			Economic activity		
	Raised bog	Degraded raised bog (transformed to another habitat after 50 years)	Transition mire	Bog woodland	Western Taiga	Natural watercourses	Ditches	Lakes or bog pools	Harvested peatland (transformed to another habitat after 25 years)	Large cranberry plantation	Harvested peatland
Crops of large cranberries/highbush blueberries	0	0	0	0	0	0	0	0	0	2	0
Crops of wild berries	0	0	0	1	1	0	0	0	0	0	0
Game	1	1	0	5	5	0	0	0	0	0	0
Amount of fish	0	0	0	0	0	0	0	1	0	0	0
Volume of timber	0	0	0	0	0	0	0	0	0	0	0
Sphagnum mosses	0	0	0	0	0	0	0	0	0	0	0
Peat for horticulture	0	0	0	0	0	0	3	0	4	0	0
Tumšā kūdra	0	0	0	0	0	0	0	0	0	0	0
Limonīts, purva dzelzs rūda	0	0	0	0	0	0	0	0	0	0	0
Amount of collected medical plants	1	1	1	2	2	0	1	0	0	0	1
Water for growing of large cranberries/highbush blueberries	0	0	0	0	0	0	0	1	0	0	0
Wood biomass for energy production	0	0	0	0	0	0	0	0	0	0	0
Soil ability to bind and accumulate nutrients	5	1	2	3	3	3	3	4	0	1	1
Amount of pollutants and aerosols diluted by ecosystem	5	0	4	5	2	5	3	5	0	1	1
Woodland density	0	2	0	3	3	0	0	0	0	0	0
Vegetation cover providing the erosion protection	5	5	5	5	4	0	0	0	1	4	1
Sediment water capacity and water storage capacity	5	3	3	4	0	1	5	5	1	4	2
Biodiversity and abundance of insect pollinators	1	0	1	2	1	0	0	0	0	1	1
Number of protected bird species	3	2	3	3	1	0	0	2	0	0	0
Species number of epigeic carabid beetles	3	4	3	3	4	0	0	0	0	2	1
Number of plant species	3	4	1	3	3	1	0	3	0	0	0
Diversity of mammals	4	1	0	1	2	2	0	2	0	0	0
Population density of ichneumon wasps	2	3	3	2	1	0	0	0	0	1	1
Thickness of hydromorphic soil	5	1	3	3	2	0	1	4	0	3	1
Chemical and ecological quality of freshwaters	0	0	0	0	0	5	0	5	0	0	0
Climate change mitigation	0	0	0	3	5	0	0	0	0	0	0
Air temperature and evaporation	5	2	5	3	5	5	2	4	1	2	1
Potential for air quality mitigation	4	3	4	3	5	3	3	3	0	1	0
Bird watching	2	2	2	2	2	2	2	2	0	0	0
Possibilities of active and passive recreation	2	2	2	1	1	1	1	1	0	0	0
Possibilities of environmental education	2	2	2	2	2	2	2	2	0	0	0

0	Ecosystem service not provided
1	Ecosystem service very low value
2	Ecosystem service low value
3	Ecosystem service low value
4	Ecosystem service high value
5	Ecosystem service very high value

6. AFTER-USE OF AREAS AFFECTED BY PEAT EXTRACTION: RECOMMENDATIONS AND EXPERIENCE OF LIFE RESTORE

6.1. Legal framework of peat extraction and related environmental aspects in Latvia

Dace Ozola

Introduction

Peat extraction is a traditional economic sector in Latvia. The first records on peat deposit research and peat extraction in the territory of Latvia dates back to the late 17th century and the beginning of 18th century (Šnore 2013). The increasing use of peat is related to its properties, as well as its potential for energy production, agriculture, horticulture, and development of new products. Formation and accumulation of peat still continues in undisturbed and slightly influenced mires. In Latvia, the peat thickness increases on average from one to two millimetres per year. The volume of peat that accumulates in mire depends on the peat-forming plant decomposition conditions, humidity and climate, therefore peat increment can vary from one year to another (Kalniņa et al. 2013). Comparing various peatland types, greater peat accumulation is usually observed in raised bogs. Peat formation and accumulation is an essential characteristic of peatlands, which determines the possibility to balance economic and nature conservation interests.

The use of peatlands is regulated by legal acts specific to several fields, such as environmental impact assessment, spatial planning, nature conservation, use of public property, use of subterranean depths and construction. Peat extraction is a strictly regulated process. Peat producer has a duty to reclaim the damaged area, and the various reclamation measures are listed in Cabinet Regulation. However, there is lack of practical guidelines for their implementation. This chapter provides a brief description of the regulatory framework and its development, taking into account that peat extraction is a complex of measures which ends with reclamation of extracted peatland.

Environmental impact assessment

In cases specified in legislation, environmental impact shall be assessed before the peat extraction, and either initial environmental impact assessment or environmental impact assessment are necessary. These procedures are governed by the Law On Environmental Impact Assessment, which aims to prevent or mitigate the negative impact caused by implementation of the proposed activities, and on the basis of Cabinet of Ministers' Regulation. Environmental impact assessment should be carried out at the earliest possible stage of planning, design and decision-making of the intended activity. The Law On Environmental Impact Assessment defines that the initial environmental assessment is necessary if peat extraction is planned in an area of 25 ha or larger; environmental impact assessment is necessary for peat extraction in an area of 150 ha or larger. If peat extraction area is being extended, and the impact assessment has not been carried out for the territory hitherto, and the extent of changes is 50% of the existing area, then an impact assessment is also necessary. Initial assessment also shall be carried out for the construction of new drainage systems if they cover more than 100 ha; reconstruction of existing drainage systems if they cover more than 500 ha; as well as afforestation and deforestation if they cover more than 50 hectares. This should be taken into account when afforestation is planned as an after-use scenario.

Environmental impact assessment[39] may be necessary also in case of mire ecosystem rehabilitation in areas where peat extraction is completed or if rewetting of drained peatland (in case if peatland is influenced by drainage but peat is not extracted) is planned in a specially protected nature area (hereinafter – protected area). The environmental impacts of the proposed action should be assessed:

39 Section 43 of the Law On Specially Protected Nature Territories.

those that can affect human beings, their health and safety, biological diversity, soil, air, water, climate, landscape, cultural and natural heritage, material values, or interaction of these sectors. An important role in the environmental impact assessment procedure is given to the public, which has a wide range of opportunities to participate. The procedure for carrying out the environmental impact assessment is available on the website of the State Environmental Bureau (www.vpvb.gov.lv) in the section "EIA".

Planning of spatial development

Peat extraction and after-use of peat extraction sites are related to spatial development planning. The purpose of Spatial Development Planning Law is to ensure such spatial development planning that would improve the quality of the living environment, ensure sustainable, effective and rational use of land and other resources, as well as purposeful and balanced development of economy.

Functional zoning and public infrastructure is specified in each local government's spatial plan, and other conditions for land use and restrictions are regulated, also regarding the extraction of mineral resources and peat. According to the Cabinet Regulation[40], the extraction of mineral resources and peat may be defined as additional land use in functional zones of local government spatial plan – "forest areas" and "agricultural areas". If peat extraction is not included in the development plans of local government, amendments to these documents may be proposed. By approving the peat extraction project, local government also evaluates the planned after-use and its compliance with the spatial development planning documents of its territory.

Nature conservation

In protected areas, peat extraction is prohibited, except for some cases. This prohibition is related to: Law On the Conservation of Species and Biotopes, Law On Specially Protected Nature Territories, and Cabinet Regulations issued pursuant to these laws. The conservation of species and habitats is ensured in protected areas and in micro-reserves (including Natura 2000 protected area network). Peat extraction is permitted only in three protected areas – Pape Nature Park, Sedas purvs Nature Reserve, and Gauja National Park – in their neutral zones or landscape protection zones. In these cases, peat extraction was commenced already before the establishment of the protected territory, and a compromise has been reached between nature conservation and economic interests. Individual Regulations on protection and use have been developed for these territories, and peat extraction is mostly allowed only in the neutral functional zone. In several protected areas, peat has been extracted prior to establishment of their conservation status, but at present it is not being continued, as it contradicts both the conservation objectives and regulatory framework of these territories (for example, in Ķemeri National Park and Melnā ezera purvs Nature Reserve).

Sedas purvs Nature Reserve is an example of successful cooperation between the peat extraction industry and nature conservation sector. Here, shallow water bodies developed after peat extraction, and they are excellent habitats for breeding waterbirds (ELLE 2006). Peat extraction in Seda Mire started in the 1930s. The amount of extracted peat increased in the 1950s when peat harvesting was carried out in large areas. In the 1990s, as socio-economic conditions changed, the volume of extraction decreased tenfold. Areas where peat extraction was discontinued or which were abandoned, gradually filled up with water, and shallow water bodies suitable for birds developed. In 1999, when the nature reserve was established, an agreement was reached between nature conservation specialists and peat producers that peat extraction would be continued and completed, at the same time meeting the needs of nature conservation. Individual Regulations on protection and use for Sedas purvs Nature Reserve[41] were developed, which define the functional zoning of nature reserve. Peat extraction is allowed in the neutral

40 Cabinet Regulation No 240 of 30 April 2013, General Regulations for the Planning, Use and Building of the Territory.

41 Cabinet Regulation No 478 of 26 May 2009, Regulation on Individual Protection and Use of Sedas Purvs Nature Reserve.

functional zone. According to expert assessment, Seda Mire could be included in the list of future Ramsar sites[42] in Latvia (ELLE 2006).

When the reclamation of peat extraction area is planned in a protected area, restoration of peatland ecosystem is likely to be carried out if the site conditions are suitable for it. Activities related to water table regulation or land use transformation in protected areas may not contradict with the purpose of establishing the protected area and with the activities which are prohibited in its territory or in the particular functional zone, as defined by the Cabinet Regulations[43]. These activities should be specified in nature protection plan. The necessity of nature protection plan is defined by the Law On Specially Protected Nature Territories. The procedure of drafting, discussion and approval of the plan is regulated by the Cabinet Regulations issued on the basis of the law[44]. The plan must include scientific information about the protected area, justification for the functional zoning, if such is necessary, and management measures for the entire territory in order to achieve its conservation objectives[45]. Depending on the category of the protected area and the particular situation, rehabilitation of peatland ecosystem may also be considered as the most appropriate type of reclamation. A written permission from the Nature Conservation Agency must be obtained for the restoration of a protected habitat[46]. Information on requesting and receiving permits is published on the website of the Nature Conservation Agency (www.daba.gov.lv). There are cases when the mire in the protected area has been affected by drainage, but no peat extraction has been carried out. In these cases, rewetting and other measures are not considered as rehabilitation (a type of reclamation) but as a restoration of a protected mire habitat (in LIFE REstore project – the demo site in Lauga Mire, neighbouring to peat extraction area), carried out in accordance to aforementioned nature protection plan, as well in accordance to regulatory enactments concerning construction.

Management of peat extraction and after-use of extracted peatlands

Management of peatlands is shared among several institutions.

Nature Conservation Agency coordinates and supervises protection and management in peatlands in protected nature areas. State, local governments and individuals as landowners are involved both in peat extraction and reclamation of extracted peatlands.

The State Environmental Service issues passports of peat deposits, sets extraction limits, issues licenses for the use of subterranean depths, controls the use of subterranean depths, and it may impose penalties if the conditions for the use of subterranean depths (including reclamation) are not met.

When completed, the result of reclamation in extracted peatland shall be approved by a commission consisting of representatives of the State Environmental Service, the relevant local government, the landowner and the extractor. The commission may also include invited experts. If the reclamation design does not include any construction works, it is accepted by the acceptance certificate when finished. Construction works are accepted in accordance with the conditions specified in the regulatory enactments concerning construction. Municipalities approve the planned reclamation and control implementation of the reclamation. “Latvian Environment, Geology and Meteorology Centre”, state Ltd, maintains geological information system and approves the deposits of peat and mineral resources. It also excludes these deposits from peat and mineral resources balance if the extraction has been completed and the prescribed after-use has been approved in accordance with established procedure[47].

42 Convention on Wetlands of International Importance especially as Waterfowl Habitat (Ramsar, 2.2.1971), ratified by Latvia in 5 April 1995, by the Law On Convention of the 2nd of February 1971, on Wetlands of International Importance especially as Waterfowl Habitat.

43 Concerning LIFE REstore pilot project in Ķemeri National Park – Cabinet Regulation No 601 of 6 September 2016, Regulation on Individual Protection and Use of Ķemeri National Park. Territories for which no Regulations on individual protection and use have been developed – Cabinet Regulation No. 264 of 16 March 2010, General Regulations on Protection and Use of Specially Protected Nature Territories.

44 Cabinet Regulation No 686 of 9 October 2007, On the Content of and Procedure Regarding the Elaboration of Nature Protection Plan for Specially Protected Nature Territory. Concerning LIFE REstore pilot project in Lauga Mire – Nature Protection plan of Laugas purvs Nature Reserve.

45 Section 18 of the Law On Specially Protected Nature Territories.

46 Cabinet Regulation No 264 of 16 March 2010, General Regulations on Protection and Use of Specially Protected Nature Territories.

47 Cabinet Regulation No 570 of 21 August, 2012, Procedures for the Extraction of Mineral Resources.

Ownership of peat deposits and peat; management of public property

In Latvia, subterranean depths, including peat resources, belong to the landowner. Property rights may be restricted if the restrictions are justified – if they are defined by law, have a legitimate purpose and are reasonable. The existence of a legitimate purpose indicates that the restriction of property rights is set for the public interest. The most common restriction on the use of subterranean depths is the prohibition on the extraction of minerals and peat, in protected areas.

The following institutions may be involved in peat deposits management as landowners or legal possessors:

- ✔ JSC "Latvijas Valsts meži" (manages state-owned land under possession of Ministry of Agriculture);
- ✔ Municipalities (including "Rīgas meži" Ltd of Rīga municipality);
- ✔ Nature Conservation Agency (manages state-owned land under possession of Ministry of Environmental Protection and Regional Development).

About two thirds (78%) of the peat extraction license areas are state-owned or public – 55% belongs to the state, and 23% to municipalities.

Figure 111 shows the distribution of peat extraction license areas by ownership status. Here, land owned by legal persons includes: capital companies of local governments; land belonging to companies; land belonging to some other legal entities.

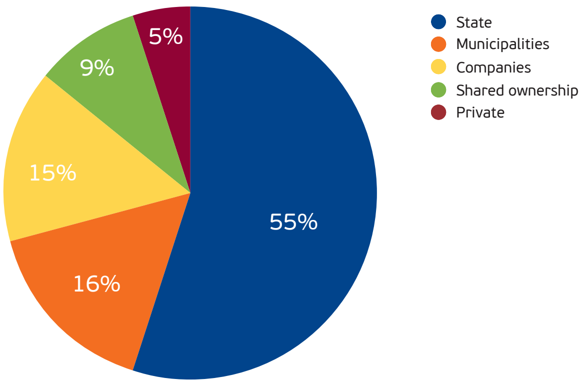

Figure 111. Distribution of peat extraction license areas by ownership status. Data source: Jansons (2016).

The basic principles for lease of state and local government (public persons) land are defined by the Law On Prevention of Squandering of the Financial Resources and Property of a Public Person. Cabinet Regulation issued on the basis of this law establishes the procedure for organizing the tender or auction for the lease of land rights, as well as the procedure for the determining and reviewing the rent. In order to encourage efficient extraction of resources and efficient use of the area, the minimum area sizes are defined for which a public tender or auction for the land lease rights of a public person is necessary, gaining the right to obtain a license. Tender or auction is mandatory if the area for peat extraction site exceeds 150 hectares[48]. If a tender is not organized, the lessor determines the rent according to the evaluation of land lease market. The land owner or legal possessor also sets out its own conditions for after-use.

If the land of a public person is leased out for peat extraction, the lessee is not entitled to derogate unilaterally from the land lease agreement, even if he does not agree to the revised price for rent. This means that the lessor and the lessee are obliged to agree either on further cooperation or on the

48 Cabinet Regulation No 696 of 6 September 2011. Procedure for the Issue of Licences for the Use of Subterranean Depths and Authorisations for the Extraction of Widespread Mineral Resources.

conditions for termination of cooperation. This standard is included in a law[49] in 2017 as an additional security for the after-use. It should be assessed together with the 2017 Amendments to the Law On Subterranean Depths. Here, the licence duration for public land lease and, therefore, the use of subterranean depths is extended from 25 years to 75 years. Consequently, the land of a public person may be leased for the use of subterranean depths for a period of time from the initiation of peat extraction to the after-use of the extraction site. During the validity period of the license, the State Environmental Service must review the terms of the license at least every 25 years. These amendments are also aimed at ensuring reclamation.

Until January 18, 2018, the rule of the Law On Subterranean Depths was in force, defining the license duration for the use of subterranean depths, as well as the duration of lease for state or local government land. For peat and mineral extraction, it was up to 25 years; for geological exploration and subsequent extraction of peat and mineral resources – for up to 30 years.

The duration of peat extraction depends on several factors, of which the volume of deposits is the most important one. It depends on the area size of the deposit and the thickness of the useful layer. For example, peat extraction in Kaigu Mire started in the 1920s and is still continuing. Thus, in many areas it is not possible to extract all the available amount of resources within the time limit which was in force until January 2018 – within 25 years (30 years together with geological exploration). At the same time, peat producer was and is obliged to perform reclamation of the extracted area.

After the end of public land lease contracts which were signed in the 1990s, peat extractors did not have the opportunity to extract the peat deposit to its full potential. Peatland ecosystem was transformed, but peat extraction was not completed, and it was also not possible to carry out the reclamation. In order to continue peat extraction in the deposit, the owner or possessor of the public land had to hold a tender or auction. At the same time, it was risky to try to rent a peat deposit for the extraction to another merchant, because, taking into account the amount and quality of the remaining peat resource, its extraction could no longer be economically feasible for another merchant. There was a serious risk that reclamation after peat extraction would not be carried out, as well as it was a risk to state and municipal budgets, as the state or local government (but not the current lessee) would have to commission and pay for the reclamation. Moreover, increased emissions of greenhouse gases (GHG) would continue from bare peat fields where peat extraction is discontinued.

Peat extraction and reclamation

The framework for peat extraction and reclamation is defined by the Law On Subterranean Depths and by the Cabinet Regulation issued on its basis. The purpose of the law is to ensure complex, efficient, environmentally-friendly and sustainable use of subterranean depths, as well as to specify the requirements for protection of subterranean depths. The law defines an obligation for peat extractors to ensure reclamation of degraded peatland at their own expense, within the time limit specified in the license. This process is supervised by the municipalities in their administrative territory. The Law On the Subterranean Depths and the Cabinet Regulations issued on the basis thereof refer to an extractor of mineral resources – a person or merchant for which a license has been issued for the use subterranean depths. It is also a subject to all legal rights and obligations, including the obligation to carry out the reclamation.

The Cabinet Regulation Procedure for the Issue of Licences for the Use of Subterranean Depths and Authorisations for the Extraction of Widespread Mineral Resources[50] defines how the State Environmental Service issues licenses for the use of subterranean depths. License is necessary both for peat exploration and extraction; most often, there are two different licenses.

49 Law On Prevention of Squandering of the Financial Resources and Property of a Public Person.

50 Cabinet Regulation No 696 of 6 September 2011, Procedure for the Issue of Licences for the Use of Subterranean Depths and Authorisations for the Extraction of Widespread Mineral Resources.

Procedure Regarding Extraction of Mineral Resources[51] defines the requirements for all stages of peat extraction works: geological exploration, geological exploration report, acceptance of peat resources by "Latvian Environment, Geology and Meteorology Centre", State Ltd, peat extraction, and reclamation. The regulation defines the requirements for peat extraction projects and the procedure for their approval. The extraction project should also include information on environmental protection measures and reclamation type. Type and measures of reclamation must be planned already during the development of peat extraction project. The planned reclamation measures must be coordinated with the local government, which examines whether it conforms to its development planning documents.

If the type of reclamation differs from that described in an extraction project, peat resource extractor must submit a reclamation design to the local government building board (pre-project material in free-form, demonstrating the intention of reclamation). The building board, upon approval of reclamation technical design, may set its own conditions.

According to Cabinet Regulation Procedures for the Extraction of Mineral Resources, the purpose of reclamation is to ensure the after-use of land after completion of extraction; to prevent threats to human health, life and the environment; to promote the integration of site into the landscape.

Reclamation can be carried out simultaneously with peat extraction, as the license area for use of subterranean depths may include both areas where peat extraction continues and areas where reclamation works are carried out. Reclamation must be initiated within a year after completing the peat extraction in the whole license area. Cabinet Regulation[52] states types of reclamation (called *rekultivācija* in national legislation in Latvian) which can be carried out in peat extraction sites:

- ✔ rehabilitation of mire ecosystem (called *renaturalizācija* in national legislation in Latvian);
- ✔ preparation for use in agriculture, for example, by establishment of berry plantations;
- ✔ preparation for use in forestry;
- ✔ creation of water bodies;
- ✔ preparation for recreation use;
- ✔ preparation for other type of after-use.

Completed reclamation works are approved by a commission established in accordance with the Cabinet Regulation.

Latvian Administrative Violations Code lays down that State Environmental Service has the power to impose fines to individuals from 70 to 700 euros, but to legal entities – from 140 to 1400 euros, for the violation of requirements specified in regulatory enactments regarding the use of subterranean depths. This means that one can be penalized for not carrying out the reclamation. According to the information provided by the municipalities on the reclamation of peat extraction sites, there have been no violations, and the requirements of the regulatory enactments and land lessors are being followed.

In many peat extraction areas, only the upper layer of peat is extracted – poorly decomposed raised bog peat, which is mainly used in horticulture. However, the deepest layers which make up one-third or even half of the peat volume often remain unused. These layers contain highly decomposed fen peat which can be used as energy source, and they are left unused because there is no demand for this type of peat. In the course of extraction, the peatland ecosystem becomes degraded, but it is not reasonable to implement reclamation measures, because the peat resource is not fully extracted. Peat continues to decompose and release greenhouse gases. Thus, also the peat resource is lost. However, reclamation measures cannot be carried out while the peat is not fully extracted, because it would contradict to the purpose of the Law On Subterranean Depths – to ensure complex, efficient and sustainable use of subterranean depths.

Reclamation experience in extracted peatlands in Latvia is described in Chapters 6.2 and 6.3.

51 Cabinet Regulation No 570 of 21 August 2012, Procedures for the Extraction of Mineral Resources.

52 Cabinet Regulation No 570 of 21 August 2012, Procedures for the Extraction of Mineral Resources.

Regulatory framework for construction and drainage related to the reclamation

Drainage of peatland is necessary in order to carry out the peat extraction. Reclamation that follows the peat extraction, in opposite, may be related to water table regulation, including rewetting. Therefore, the regulatory framework concerning drainage must be taken into account. The purpose of Amelioration Law is to ensure such mechanism for the management of drainage systems, which promotes sustainable management and use of natural resources, ensures the water regime necessary for the safety and welfare of people, development of infrastructure, as well as the construction, operation, maintenance and management of drainage systems in rural and urban areas. Drainage systems are constructed and reconstructed in accordance with the Construction Law and the Cabinet Regulations issued on its basis[53]. If construction work is necessary for reclamation of extracted peatlands or restoration of drained peatlands, it must be coordinated in accordance with the requirements specified in the regulatory enactments regulating construction.

Conclusions

Regulations set the basic requirements for the reclamation of extracted peatlands. They lay down the obligation to carry out the reclamation of the peat extraction site, the purpose of after-use, and list the possible after-use scenarios. There is no definition of reclamation in the national legislation. This can lead to misunderstandings, as it is not clear what exactly the extractor needs to do and what the landowner does if the land is leased. During the compilation of this book, the draft amendment to the Law On Subterranean Depths was developed, and it includes the explanation of the term "reclamation" (called *rekultivācija* in the national legislation in Latvian): "a set of actions to be performed after extraction of peat and mineral resources in order to prepare an extraction site for further use of land according to the planned land use type". In this case the land use type means the intention of the landowner – for what purpose the land will be used after the extraction of peat or mineral resources, taking into account the legislation and requirements set in the territory development plan: for forestry, for agriculture or for other purposes. This supplement to the law, together with the already mentioned obligation for the peat and mineral extractors "to recover the damage caused by the use of subterranean depths at their own expense within the time limit specified in the license", would clearly define the responsibilities.

So far, recommendations for implementation of reclamation measures set in legislation were absent in Latvia. Therefore, reclamation recommendations included in the Chapter 6.2 of this book will be a useful tool for planning of after-use and reclamation. It is currently too early to judge whether recommendations should be included in legislation. In future, the experience and knowledge will grow, and recommendations can be improved or changed. However, if they will be included in legislation, their modification will not be flexible and will take a long time.

Recommendations for implementing various after-use scenarios should be published on websites of responsible or involved institutions, for example: Ministry of Environmental Protection and Regional Development, Ministry of Agriculture, State Environmental Service, Nature Conservation Agency, "Latvian Environment, Geology and Meteorology Centre", State Ltd, JSC "Latvijas valsts meži", Latvian Association of Local and Regional Governments, and the municipalities on whose territories peat extraction takes place.

The sooner the peat extraction will be completed and the site will be reclaimed, i.e. prepared for another land use, the shorter will be the time of GHG emissions caused by peat extraction. However, currently in some cases peat extraction cannot be completed, because there is no demand for highly decomposed fen peat. Reclamation of extracted peatland cannot be carried out while the resource extraction is not completed, as it contradicts the purpose of the Law On Subterranean Depths – to ensure rational use of subterranean depths. The use of raised bog peat for energy or other purposes, such as

53 Cabinet Regulation No 500 of 19 August 2014, General Construction Regulations; Cabinet Regulation No 550 of 16th September 2014, Regulation for Hydraulic Constructions and Drainage Structures; Cabinet Regulation No 329 of 30 June 2015 Regulation on Latvian Construction Standard LBN 224-15 "Amelioration Systems and Hydraulic Structures".

production of high added value products, would contribute to the reclamation of peat extraction sites and to the reduction of GHG emissions caused by peat extraction. Peat, similarly as wood, is a solid fuel of plant origin, and the chemical composition of both fuels is similar. Also other characteristics of these fuels are similar, such as combustion heat, humidity, specific weight and combustion technologies. However, the use of peat for energy also generates significant GHG emissions. Therefore, this discussion should be continued by assessing various aspects of gains and losses (environment, including GHG emissions, economic benefits, energy efficiency, national energy independence, and others).

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6.2. After-use scenarios suitable for Latvia

6.2.1. Introduction

Ingrīda Krīgere, Laimdota Kalniņa

According to national legislation, reclamation is a complex of measures applied in a mining area to prepare it to a level of quality suitable for further use according to its land use purpose. The choice of reclamation measures (after-use scenarios) depends on many varying factors (e.g. political situation, owner's interest, market demand), and relatively constant factors (e.g. relief, residual peat layer properties, groundwater table).

According to the experience by the members of Latvian Peat Association, peat production at an individual extraction site takes about 75 years. Reclamation shall be planned before beginning peat extraction, during the development of peat extraction design. However, the initially planned reclamation measures may change, and political and economic system and land ownership may change as well. Reclamation measures and consequently the after-use scenario depend on site conditions, landowner's intentions and land use determined in the spatial plan of the respective municipality. If peat extraction is completed or discontinued several decades ago, and the area is not reclaimed or the reclamation has failed, the landowner must decide on further land use and reclamation type. According to the inventory carried out by LIFE REstore project (Chapter 4.5), unreclaimed peat extraction areas in Latvia cover about 18,000 hectares. Here, before reclamation, residual peat layer must be estimated, and it must be decided if it is economically reasonable to continue peat extraction and reclaim the area later.

Each harvested peatland differs from one another, therefore the initial evaluation of site conditions is necessary to understand the problems and find the best solutions for further activities. In order to select the appropriate after-use scenario for the particular site, there is a minimum set of characteristics to be evaluated, such as peat type in the upper layer; thickness of residual peat layer; pH of upper peat layer; average groundwater table; the average number of days per year when the area is flooded; peat decomposition degree; composition of sediments in the mineral ground; amount of tree stumps.

Peat producer must follow the requirements and technical solutions included in peat extraction design or in the reclamation design, in order to prepare a site for the planned land use type after peat extraction. The reclamation requirements are usually included also in land lease contract according to which land is leased for mineral and peat extraction. Peat extraction project describes the condition which should be achieved in site before reclamation; sets the thickness of residual peat layer; the site surface must be levelled. Afterwards, the reclamation design is developed and, depending on the after-use scenario, it must include further activities which must be implemented by the landowner (unless the land lease contract states otherwise).

By fulfilling these conditions, the peat producer has prepared the post-mining area for another land use type. Landowner must carry out further land management, for example, establishment of suitable drainage system, sowing and maintenance of perennial grasslands, cultivation and maintenance of paludicultures, planting and maintenance of forest, management of water bodies. The preparation of territories for after-use (agriculture, forestry, pond farming, recreation, mire restoration, and other purposes) involves several steps in a logical sequence. This chapter deals with a set of measures and necessary activities, although several of them include also further management and go beyond the frame of reclamation and thus also the responsibility of peat extractor.

This chapter provides information on eight after-use scenarios which are suitable for Latvia: croplands and perennial sown grasslands; plantations of high cranberries and highbush and lowbush blueberries; paludicultures; afforestation; water bodies; rehabilitation of peatland ecosystem. Descriptions of reclamation measures include the summarized and evaluated experience gained in peat extraction sector, as well as case studies and research described in literature, and information provided by experts and professionals. Four after-use scenarios were tested in LIFE REstore demo sites (see Chapter 6.3). For selecting the most appropriate after-use scenario, a support tool was developed by the LIFE REstore project – the optimization model (see Chapter 6.4).

6.2.2. Establishment of cropland

Ingrīda Krīgere, Inārs Dreimanis, Dace Siliņa, Laimdota Kalniņa, Andis Lazdiņš

This after-use scenario covers conversion of harvested peatland into cropland for cultivation of arable crops, and the management of land according to the new land use type. This includes the modification and maintenance of drainage systems for the operation of cropland. The crops that can be grown on peat soils are cereals, legumes, fibre crops, oil plants, various grasses, vegetables, culinary herbs, ornamental plants.

The further land use purpose of the real estate is land with agriculture as the main economic activity. Real estate code – 0101, land use type – cropland[54].

Conditions when establishment of cropland is possible

Peat type in the upper layer	transitional mire or fen-type peat (thickness of transitional mire peat < 0.25 m)
Residual peat layer thickness	< 0.5 m
pH of upper layer peat	5–8
Peat decomposition degree	moderately and well decomposed peat
Average groundwater table below the surface	< 0.7–1.0 m
Average number of days in a year when the area could be flooded	0
Amount of stumps in peat layer	should not exceed 3.0%; establishment and further management of cropland may be difficult due to large amount of tree trunks and stumps

54 Land use types here and below – in accordance with the Cabinet Regulations of June 20, 2006, No 496 “The classification of the objectives of the land use of real estate”.

Harvested peatlands with residual fen peat are the most suitable for establishing arable land, because the fen peat is rich in mineral compounds, carbonates and nitrogen, and substrate is poorly acidic, neutral or alkaline (pH 5.5–7.4) (Krūmiņš et al. 2013). Through cultivation of peatlands with residual fen type peat, relatively fertile soils can be created, which are particularly useful for establishment of cultivated grasslands and for growing of vegetables. Transitional mire peat can be used if the layer is shallow and the fen peat lies below the transitional mire peat. Transitional mire substrates usually are poorly acidic (pH ~4.5) (Krūmiņš et al. 2013), therefore liming might be necessary depending on the requirements of the certain crops.

If the establishment of cropland is planned in a site where peat extraction has been discontinued, and the entire useful peat deposit has not been harvested, and transitional mire peat lies above the fen peat, it is recommended that the thickness of fen peat should be less than 0.25 metres. In this case, transitional mire peat will mix with fen peat in a result of agro-technical operations, creating more favourable growth conditions for the selected crops.

The recommended maximum thickness of peat above the mineral ground is 0.5 metres. In peatlands where peat was extracted in the 20th century and was discontinued without reclamation, the thickness of residual peat layer may be higher. In such cases, completion of peat extraction must be considered, leaving a 0.5 m thick layer of peat, thus also contributing to efficient use of peat resources. While extracting peat for commercial use, it is also possible to prepare the selected site for cultivation of potential crops, to obtain financial resources from the sale of peat, and at the same time to adapt the site to the planned land use by restoration of drainage system of peat extraction fields.

The condition of drainage system in the area to be reclaimed as well as its suitability for the planned land use, arrangement and functionality is also essential for establishment of cropland. The hydrological and hydrogeological conditions of the area, as well as the composition of the sediments in mire bottom should be taken into account. Establishment of cropland is possible on permeable or moderately permeable mineral sediments.

Planning and preparation stage

Several steps should be taken if establishment of cropland is planned in a harvested peatland.

- ✔ The compliance of planned after-use measures with spatial planning documents of local municipality must be evaluated.
- ✔ In case if peat extraction still continues in the area, the compliance of the planned after-use scenario with documents of use of subterranean depths must be evaluated.
- ✔ Reclamation design must be developed and approved in accordance with the procedures set in legislation.
- ✔ Construction designs for drainage systems and other related constructions must be developed and approved in accordance with the procedures set in legislation.
- ✔ The thickness of residual peat layer necessary for creation of cropland and its further management must be specified if a new design for use of subterranean depths is being developed or the modifications in the existing design are planned.
- ✔ If the establishment of cropland is planned in a cutaway peatland abandoned long time ago, it must be clarified if environmental impact assessment or initial environmental impact assessment is necessary in accordance with legislation.
- ✔ Reconstruction or modifications of the drainage system can be necessary in order to ensure appropriate soil water regime and aeration in soil.
- ✔ Vegetation must be removed from extracted peatlands that have been abandoned long time ago.
- ✔ Remains of tree trunks and stumps must be removed.

- ✔ Land surface must be levelled.
- ✔ Field ditches must be filled in if specified in the reclamation design or in peat extraction design.
- ✔ Tillage of peat soil (recommended depth: 30–35 cm) is necessary to invert the soil, to leave no remains of plants on the top of the plough. Ploughing should be as smooth as possible and ploughing depth must be uniform (depth variations should not exceed 2–3 cm).
- ✔ Stumps and trunks exposed after tillage must be removed from the field.
- ✔ After the first ploughing, the field must be treated with disc cultivators.
- ✔ After the initial treatment, soil must be compacted, and micro-depressions must be smoothened.
- ✔ Soil amelioration (for example, fertilization, liming) might be necessary.

Preparation and maintenance of drainage system

In cropland established in the former peat extraction area, the arrangement of drainage system must ensure the necessary air and moisture conditions for the crops during the growing season. The average groundwater table should not exceed 0.7–1.0 m (Aire et al. 1970). Water table can be controlled by drainage which can be modified if necessary, or a new drainage network can be established. By planning the arrangement of ditches, relationship between the existing and planned ditches and their depth and distance between ditches must be taken into account, as well as thickness of the residual peat layer and composition of mineral sediments below the peat layer. This will allow determining the optimal depth and distance between the ditches (Eriņš 1966).

In addition, the technical condition of the drainage network and its hydro-technical structures (culverts) should be evaluated, as the drainage system of peat extraction site is closely connected to network of collecting ditches. This assessment will provide additional information for making the decision on solutions for draining the excess water into the collecting ditches, i.e. whether achieving appropriate groundwater table will not be cumbered by hydro-technical constructions.

An open drainage system should be preferred as surface ditches drain the surface water and receive groundwater faster, and its construction and maintenance costs are lower than those for subsurface drainage system.

Establishment of subsurface drainage system is an alternative to surface drainage of cropland. With a closed system of drainage pipes, it is possible to achieve a more homogeneous soil moisture regime, as well as undisturbed movement of agricultural machines. The drainage system does not occupy the usable land area. In well-drained areas, plant roots reach deeper soil layers and use nutrients more effectively (Šnore 2013).

It is recommended to involve certified professionals in assessment of hydrological conditions and drainage options in the area to be reclaimed.

Surface preparation and soil amelioration

If the establishment of cropland is planned as after-use scenario in areas where peat extraction is not started yet or is ongoing, it is recommended to use peat milling technology as the final stage for peat extraction for at least 2–3 years. This will ensure that land surface will be smooth and additional levelling, milling and other works will not be necessary, thus reducing the cost of site preparation.

If the establishment of cropland is planned in peat extraction areas abandoned for a long time, the amount of stumps must be determined in the residual peat layer. Usually there is a certain amount of wood remains in the peat deposit. The use of area for agriculture will be difficult in sites with high proportion of stumps, as removal of stumps and roots will be necessary frequently, and agro-technical works will be encumbered. If the residual peat layer is composed by transitional mire peat, soil liming will be necessary, because the transitional peat soils are acidic ($pH < 5$).

Bare peat surface absorbs solar radiation very well. In the spring, the upper layer heats up rapidly, while the frozen peat in deeper layers melts very slowly. This condition should be taken into account when deciding on crops to be cultivated, especially when planning sowing in period of spring-time frosts. In autumn, frosts on peat soils begin 10–15 days earlier than on mineral soils.

Contribution to climate change mitigation

The potential impact on climate change should be taken into account when considering cropland as an after-use scenario. The impact on the greenhouse gas (GHG) emissions was estimated by LIFE REstore project for a 30-year period following the establishment of cropland, assuming that it is implemented in an area where peat extraction has been discontinued recently and vegetation has not yet developed, but the topsoil is formed by the fertile fen peat. After establishment of cropland, GHG emissions will increase by 14.6 t CO_2 eq./ha^{-1} year compared to the initial condition prior to reclamation. Total GHG emissions from cropland in developed peatlands during the calculation period correspond to 20.9 t CO_2 eq./ha^{-1} year. GHG emission calculations do not include emissions from fertilizers, which, depending on the applied doses, can significantly increase N_2O emissions from soil. These emissions are accounted in the agricultural sector using a unified calculation method for converting the applied fertilizer amount into direct and indirect N_2O emissions. Establishment of croplands for intensive cultivation generates the highest GHG emissions compared to other after-use scenarios. For more on GHG emissions, see Chapters 3.1 and 3.2.

Indications of successful reclamation

A drainage system that ensures water regime and aeration optimal for cultivation of soil and growing of crops. Tree stumps and trunks are removed; the surface of fields is even.

Indications of unsuccessful reclamation

Drainage system does not provide water regime and aeration optimal for cultivation of soil and growing of crops. Field surface is uneven, with micro-depressions.

Advantages

The reclaimed area becomes available for a conventional or organic agriculture, which provides economic and social benefits.

Disadvantages

Peatlands is turned into heavily exploited cropland that becomes a significant source of GHG emissions.

Possible works and their preliminary costs

Possible necessary works and their preliminary costs are summarized in Chapter 6.2.10.

Experience in Latvia

There are several cutaway peatlands in Latvia which currently are used for conventional agricultural activity. The largest territories are located in the Mārupe municipality (for example, the area of the former Cena Mire massif).

6.2.3. Establishment of perennial sown grasslands

Ingrīda Krīgere, Inārs Dreimanis, Dace Siliņa, Laimdota Kalniņa, Andis Lazdiņš

This after-use scenario includes conversion of harvested peatlands into croplands by establishing perennial sown grasslands that are afterwards regularly mown or grazed. In this book, perennial grassland (either meadow, or pasture) is considered an area that is dominated by herbaceous plants. Semi-natural and sown grasslands are distinguished. Here, in terms of reclamation, the further information applies only to sown grasslands and their establishment.

Perennial sown grasslands are human-created, maintained grasslands. The environmental conditions are controlled by agro-technical measures (fertilization, cultivation, etc.) (Anševica et al. 2016). The vegetation of perennial sown grasslands consists mainly of perennial grasses, legumes, forbs and sedges (hereinafter all together referred to as grasses and forbs). Perennial sown grasslands are used for forage and for energy biomass production (Figures 112, 113).

The further purpose of land use is area with agriculture as the main economic activity (code 0101); land use type – meadows or pastures.

Conditions when establishment of perennial sown grasslands is possible

Peat type in the upper layer	transitional mire or fen peat (thickness of transitional mire residual peat < 0.25 m)
Residual peat layer thickness	< 0.5 m
pH of upper layer peat	5–8
Peat decomposition degree	moderately to well decomposed peat
Average groundwater table below the surface	perennial grasses and forbs for haymaking: 0.70–0.75 m; perennial grasses and forbs for pasturing: 0.80–0.90 m
Average number of days in a year when the area could be flooded	the area may be seasonally temporarily flooded, but should not be permanently water-logged
Amount of stumps in peat layer	< 3.0%

Fens are the most suitable type of peatlands for agricultural use, as their soils are rich in mineral substances, possibly also with carbonates and nitrogen, and are less acidic (pH 5.5–7.4), compared to transitional mires and raised bogs (Krūmiņš et al. 2013). If peat extraction is discontinued, but the entire useful peat deposit is not extracted, and transitional mire peat lies above the fen peat, its thickness should not exceed 0.25 m, which, in a result of agro-technical measures, will be mixed with the fen peat, forming more favourable growing conditions for selected plant species.

Perennial sown grasslands can also be established on transitional mire peat soils which are slightly more acidic than fen peat soils (pH 4–5) (Лиштван 1996). If peat pH value is 4.0–4.3, it is very likely that soil liming will be necessary, depending on requirements of plant species and variety (Anševica et al. 2016).

Perennial sown grasslands are highly productive, and relatively tolerant to varying soil conditions. Several graminoids (for example, reed canary grass *Phalaris arundinacea*, timothy-grass *Phleum pratense*, tall fescue *Festuca arundinacea*) are suitable for growing in peaty, wet, periodically water-logged soils. The strong root system of grasses and forbs has a positive effect on soil quality. It promotes the formation of persistent sod and captures carbon, preserving and increasing the amount of organic matter, and also reducing soil erosion.

Figure 112. Pasture in former peat extraction area in the Netherlands. Photo: L. Kalniņa.

Figure 113. Perennial grassland with reed canary grass *Phalaris arundinacea* in former peat extraction area in the surroundings of Olaine, Central Latvia. Photo: A. Priede.

Grasses and forbs are energy-efficient. Relatively low financial investments are necessary for grasslands, and specialized equipment is not necessary. "Traditional" agricultural machines can be used for management.

Several grass and forb species used in sown perennial grasslands, including reed canary grass *Phalaris arundinacea*, are similar to other energy crops, such as rape, in terms of biomass production and quality. The duration of exploitation of a territory cultivated with *Phalaris arundinacea* is 8–10 years and more. The maximum yield (8–10 t of dry matter per hectare) of this graminoid can be achieved in the second and third year after sowing. Biomass of *Phalaris arundinacea* can be used as raw material for biofuel, for production of high quality chemical pulp, and as the replacement of birch timber for the pulp industry.

The most important condition for the implementation of this after-use scenario is the proper assessment of site hydrological conditions. Characteristics that have to be evaluated include water supply to the area, composition of mineral sediments in the bottom of peatland; technical condition of drainage system (ditches) and hydro-technical constructions (culverts); condition of peat extraction drainage system; its suitability for the planned land use.

Planning and preparation

Several steps should be taken if the establishment of perennial sown grassland is planned in harvested peatlands.

- ✔ Compliance of planned reclamation measures with spatial planning documents of local municipality must be evaluated.
- ✔ In case if peat extraction still continues in site, compliance of planned after-use scenario with documents of use of subterranean depths must be evaluated.
- ✔ Reclamation design must be developed and approved in accordance with the procedures set by legislation.
- ✔ Construction design of drainage and irrigation systems and other related constructions must be developed and approved in accordance with the procedures set by legislation.
- ✔ The preservation of residual peat layer of necessary thickness must be specified when new project on use of subterranean depths is being developed, or the existing project is amended.
- ✔ If the reclamation measures are planned in an extracted peatland that is abandoned long time ago, environmental impact assessment or initial environmental impact assessment is necessary in accordance with legislation.

- ✔ Reconstruction or modification of drainage system can be necessary in order to ensure appropriate soil water regime and aeration which is optimal for growing of cultivated grasses and forbs.
- ✔ Vegetation must be removed from extracted peatlands that are abandoned long time ago.
- ✔ Remains of tree trunks and stumps must be removed.
- ✔ Land surface must be levelled.
- ✔ Field ditches must be filled if specified in reclamation design or peat extraction design.

Preparation and maintenance of drainage system

In perennial grasslands which are established in former peat extraction areas, the arrangement of drainage system must ensure the necessary aeration and moisture conditions for the cultivated herbs and forbs during the growing season. The average groundwater table should be lower than 0.7–1.0 m (Aire et al. 1970). The necessary conditions can be achieved by constructing ditches with optimal depth and spacing. By planning the arrangement of ditches, residual peat layer thickness and composition of sediments below the peat layer must be considered. This will help to determine the optimal depth and distance between ditches or drains (Eriņš 1966).

In addition, the technical condition of the drainage network (ditches of various types) and its hydro-technical structures (culverts) should be evaluated, as the drainage system of peat extraction site is connected to the network of collecting ditches. This assessment will provide additional information for making the decision about solutions for draining the excess water to the collecting ditches, i.e. whether achieving appropriate groundwater table will not be cumbered by hydro-technical constructions.

The establishment of closed or open drainage system must be planned according to land use purpose. In case of open drainage system, surface ditches drain the surface water and receive groundwater faster, and their construction and maintenance costs are lower than for the subsurface drainage system. When installing subsurface drainage pipes, it is possible to achieve a more homogeneous soil moisture regime, as well as undisturbed movement of agricultural machines. Subsurface drainage system does not occupy the usable land area. Plant roots reach deeper soil layers and use the nutrients more effectively. Establishment of larger homogeneous grassland areas, mowing, pasturing, and movement of herd are easier and more efficient (Šnore 2013).

It is recommended to involve certified professionals in assessment of hydrological conditions and drainage options in the area to be reclaimed.

Surface preparation and soil amelioration

If establishment of perennial sown grasslands is planned as an after-use scenario in areas where peat extraction is not started yet or is still ongoing, it is recommended to use peat milling technique as the final stage for peat extraction for at least 2–3 years. This will ensure that land surface will be smooth and additional levelling, milling and other works will not be necessary, thus reducing the cost of site preparation.

If the establishment of perennial sown grasslands is planned in peat extraction areas abandoned for longer time, the amount of stumps must be determined in peat layer. The use of area for agriculture will be difficult in sites with high proportion of stumps, because removal of stumps and roots may be necessary, and agro-technical measures will be encumbered.

Tillage of peat soils (recommended depth: 30–35 cm) is necessary to invert the soil completely, to leave no remains of plants on soil surface. Ploughing should be as smooth as possible and ploughing depth must be uniform (depth variations should not exceed 2–3 cm). Stumps and trunks and tree roots exposed after tillage must be removed. After the first ploughing, field must be treated with disc cultivators, soil must be compacted, and micro-depressions must be smoothened.

Soil amelioration (for example, liming, application of slurry or digestate) might be necessary. If residual peat layer consists also of transitional mire peat, soil liming is necessary as the transitional mire peat soils are acidic (pH < 5).

Sowing of grass seeds

Site must be prepared for grass seed sowing in accordance with the soil granulometric composition, structure, moisture conditions, previous soil treatment, as well as the type and technique of sowing. For species with large seeds (for example, *Lolium perenne*, *Bromus inermis*, *Festuca pratensis*, *F. arundinacea*), seeds in loose soils are planted at a depth of 2.5–3.5 cm; and at 1.5–2.5 cm in heavy soils.

Mixtures containing seeds of both groups are sown at a depth of 1.5–2.5 centimetres.

It should be noted that under normal moisture conditions, grass seeds do not germinate below 4–5 cm depth.

Peat absorbs solar radiation very well; peat soils tend to warm up more slowly and cool faster than mineral soils. In the spring, the surface layer heats up very rapidly, while the frozen peat in deeper layers melt very slowly due to low thermal conductivity. These circumstances should be taken into account when planning the time of planting. In autumn, frosts on peat soils begin 10–15 days earlier than on mineral soils. Seeds of grasses and forbs are particularly susceptible to freezing in time of sprouting. If the temperature is below -3 C, sprouts may perish (Anševica et al. 2016).

Contribution to climate change mitigation

The potential impact on climate change should be evaluated when considering establishment of perennial sown grassland in cutaway peatland. Within LIFE REstore project, the impact on GHG emissions was assessed for a period of 30 years after reclamation, assuming that perennial grasslands are established in areas where peat extraction has been completed recently and ground vegetation has not yet developed, and the topsoil consists of fertile transitional mire and fen type peat. After establishment of perennial sown grasslands, GHG emissions would increase by 8 t CO_2 eq./ha^{-1} year. Total GHG emissions in the calculation period correspond to 14.3 t CO_2 eq./ha^{-1} year. Establishment of perennial sown grasslands create high GHG emissions if compared to other after-use scenarios (LIFE REstore project data). For more on GHG emissions, see Chapters 3.1 and 3.2.

Indications of successful reclamation

There is a drainage system that is able to provide water regime and aeration optimal for growing of grasses and for grassland management.

There is a high quality sward of perennial grasses after the successful implementation of this after-use scenario.

Indications of unsuccessful reclamation

The establishment of perennial sown grassland in extracted peatland can be considered as unsuccessful if the sown grasses fail to establish.

The drainage systems do not provide the optimal water and aeration regime necessary for growth of grasses and for field management. The soils are water-logged for a long time, paludification can be observed.

Advantages

The reclaimed area becomes available for a conventional or organic agricultural activities, which provides economic and social benefits.

Disadvantages

Perennial sown grassland is a heavily exploited cropland, and it becomes a significant source of GHG emissions.

Possible works and their preliminary costs

Possible necessary works and their preliminary costs are summarized in Chapter 6.2.10.

Experience in Latvia and abroad

There are several former peat extraction areas in Latvia, where intensive agricultural activity is being carried out and perennial cultivated grasslands are established. Such areas are, for example, the peatland massif around Cena Mire in Olaine municipality (Figure 113) and surroundings of Mārupe village. There is a vast experience in the conversion of cutaway peatlands into perennial sown grasslands in the Netherlands (Figure 112).

6.2.4. Establishment of large cranberry plantations

Ingrīda Krīgere, Dace Siliņa, Inārs Dreimanis, Laimdota Kalniņa, Andis Lazdiņš

This after-use scenario includes conversion of harvested peatlands into croplands where large cranberries *Vaccinium macrocarpon* are cultivated (Figures 114, 115). Large cranberries are evergreen dwarf shrubs of *Ericaceae* family. For their cultivation, optimal soil pH value is 4–5, and organic matter content is at least 3%.

After the implementation of this after-use scenario, the land use purpose is land on which agriculture is the main economic activity; land use type – orchards (code – 0101).

Figure 114. Flowering large cranberry. Photo: D. Siliņa.

Figure 115. Fruits of large cranberry. Photo: M. Pakalne.

Conditions when establishment of large cranberry plantations is possible

Peat type in the upper layer	raised bog peat
Residual peat layer thickness	not important; large cranberries can be cultivated also in mineral soil (sand, sandy loam, light loam) if appropriate soil pH can be ensured); optimum – 0.5 m
pH of upper layer peat	3.5–4.5
Peat decomposition degree	poorly decomposed
Average groundwater table below the surface	0.5 m on average
Average number of days in a year when the area could be flooded	0
Amount of stumps in peat layer	< 3%

Planning and preparation

Several steps should be taken when planning cultivation of large cranberries in harvested peatlands.

- ✔ Compliance of planned reclamation measures with spatial planning documents of local municipality must be evaluated.
- ✔ In case if peat extraction is ongoing, compliance of the planned after-use scenario with documents of use of subterranean depths must be evaluated.
- ✔ Reclamation design must be developed and approved in accordance with the procedures set by legislation.
- ✔ Design for the plantation must be developed.
- ✔ Construction design of drainage and irrigation systems and other related constructions must be developed and approved in accordance with the procedures set by legislation.
- ✔ If a new design for peat extraction is being developed or modification in the existing design is planned, the preservation of 0.5 m thick residual peat layer must be planned (optimal for large cranberry plantation).
- ✔ The distance between drains remaining after peat extraction must ensure the optimal moisture regime for cranberries.
- ✔ In unreclaimed cutaway peatlands that have been abandoned for a longer time, vegetation as well as remains of tree trunks and stumps must be removed.
- ✔ Peat surface must be levelled; the slope of surface should not exceed 2%;
- ✔ If necessary, the drainage system must be restored or reconstructed. Filling in of drains is necessary if specified in the reclamation design or peat extraction design.
- ✔ If necessary, ponds for watering of large cranberries must be established in the planned plantation area or surrounding areas.
- ✔ After removal of vegetation and surface levelling, soil cultivation is necessary.
- ✔ Soil nutrient tests and, if necessary, soil fertilization should be done.
- ✔ Technological access roads must be established.
- ✔ Surface irrigation system must be constructed.
- ✔ Establishment of early warning frost detection system is recommended (it allows a significant increase in yield).

Establishment and maintenance of drainage system

The drainage system should provide the average groundwater table at about 0.5 m below the soil surface. Depending on the circumstances in the particular site, the drainage system must be reconstructed or established to ensure appropriate moisture for large cranberries.

If there are no artificial or natural water bodies in the plantation area or in its surroundings, they must be created as sufficient irrigation is an essential prerequisite for successful cranberry production.

Surface preparation and soil amelioration

The condition of land surface is important for planting of large cranberries. Land surface must be smooth, without micro-depressions or elevations. If the surface is uneven, smoothing is necessary to a level that surface slope does not exceed 2%. This allows to protect the plants more effectively against frost and to provide an appropriate moisture regime; these are one of the main factors influencing the expected yield. After surface levelling, subsoiling is necessary, at an average depth of 0.4 m (Silava 2016).

If the establishment of large cranberry plantations is planned in areas where peat extraction is not started yet or is ongoing, it is recommended to use peat milling technique as the final stage in peat extraction for at least 2–3 years. This will ensure that land surface will be smooth and additional levelling, milling and other works will not be necessary, thus reducing the cost of site preparation.

In areas where peat extraction has been discontinued several decades ago, site is abandoned and not reclaimed, vegetation and trees must be removed, and tree roots have to be extracted. If there are stumps in the upper peat layer, they must be removed.

Before planting of cranberry vines or rooted cuttings, soil nutrient testing is necessary. This information helps to assess soil fertility, growth potential of large cranberries, and the need for soil fertilization. Types and amounts of fertilizers depend on the amount of nutrients in the peat and properties of peat, and they must be adapted to the requirements for cranberry growth.

If the soil pH value in the plantations is below 3.5, i.e. conditions are not optimal for cranberry growth, soil liming is necessary (Āboliņš et al. 2012). For large cranberries, the optimal soil pH_{KCl} is 4.5 ± 0.3. Disturbances in iron and other micronutrient uptake start at pHKCl above 5.2; calcium deficiency starts at 4.0 and below. Application with gypsum provides plant roots with calcium without significant changes of pH value in peat. If large cranberries are planted in spring, 1–1.2 t of gypsum per hectare should be applied in the autumn before planting. Gypsum should be applied evenly, spreading it across the field. The maintenance dose of gypsum is 300–500 kg/ha. Amendment of gypsum into peat does not change peat pH value because gypsum is neutral. Gypsum contains calcium, sulphur and also other nutrients at low concentrations. Gypsum must be applied in the previous year before the large cranberries are planted, to reduce sulphate concentrations (Osvalde et al. 2011).

Large cranberries must be fertilised in spring and early summer (from April to mid-June).

Planting of large cranberries

Large cranberries can be planted with cranberry vines, spreading them evenly across the field. In small areas, also rooted cranberry cuttings can be planted. Cranberries are planted from May to mid-June. For planting of one hectare, 2.5 to 3 t or 20,000 rooted cuttings are necessary. The first harvest is expected in the third year after planting, whereas regular harvest – starting from the sixth year, when it is possible to get 14–40 t on average (maximum – 56 t) of berries from hectare. Large cranberries can be grown and harvested in the same place for 50–100 years (ZM 2011).

Large cranberry vines can be planted into the soil by discs or by cutter. Planting of vines by cutter is the preferred and economically most advantageous method because part of vines perishes when worked into the soil by discs; they are not completely pressed into the peat, and do not establish roots. For the mulching of plantations, it is recommended to use sphagnum peat. In sites where irrigation system is not established, coniferous sawdust can be applied (3–4 cm layer) (Osvalde et al. 2011).

After spreading of vines, the entire field should be treated with a cutter at a depth of about 3 cm, and watered. The establishment of surface irrigation system is recommended. Although its construction costs are high, experience shows that yields can be small and uneven without it. Using irrigation system, it is easier to avoid frost damage (if plantation is watered before frosts, plants can be protected from rapid temperature fluctuations and cell damage, as water absorbs heat) and to withstand prolonged periods of drought, significantly increasing the yield. For the construction of irrigation system, a pond must be located nearby. It is preferable that water from plantations is drained during the rainfall to water supply site, and, if necessary, supplied to the plantations using pumps and pipelines.

When berry plantations are established, it is advisable to collaborate with beekeepers. Pollination of plants will increase cranberry yield.

Contribution to climate change mitigation

The potential impact on climate change should also be evaluated when considering large cranberry plantations as the after-use scenario. The impact on GHG emissions was estimated by LIFE REstore project for a 30-year period following the establishment of large cranberry plantations, assuming that these measures are implemented in an area where peat extraction has been discontinued recently and vegetation has not yet developed, but the topsoil consists of raised bog peat poor in nutrients. After reclamation, GHG emissions will decrease by 3.4 t CO_2 eq./ha^{-1} year compared to the initial condition. Total GHG emissions from large cranberry plantations during the calculation period correspond to 2.9 t CO_2 eq./ha^{-1} year. GHG emission calculations do not include emissions from fertilizers, which, depending on the applied doses, can significantly increase N_2O emissions from the soil. These emissions are accounted in the agricultural sector using a calculation for converting the applied fertilizer amount into direct and indirect N_2O emissions (LIFE REstore project data). For more on GHG emissions, see Chapters 3.1 and 3.2.

Indications of successful reclamation

The area is flat, there is a drainage system that meets the requirements of large cranberries. The entire surface of field is evenly covered by large cranberries.

Indications of unsuccessful reclamation

The area is flooded for a long time; the surface is uneven. Drainage system is not operating well, or the moisture conditions are unsuitable for growing large cranberries.

Advantages

After peat extraction, the area is used for economic activities that raise employment and income. In properly managed plantations, the topsoil is completely covered by large cranberry plants, thus the GHG emissions are reduced.

Disadvantages

GHG emissions are increased if fields are fertilized for higher yields. However, in case of appropriate timing and doses, a significant increase in emissions is not expected.

Possible works and their preliminary costs

Possible necessary works and their preliminary costs are summarized in Chapter 6.2.10.

Experience in Latvia

Experimental cultivation of large cranberries started before 1990, but establishment of large cranberry plantations in cutaway peatlands started in 2003 (Maltenieks 2008). Experience and knowledge in cultivating large cranberries in large areas is already available. Large cranberries in the former peat extraction sites (Figure 116) are planted in Līvbērze rural territory (Jelgava municipality), Gaujiena rural territory (Ape municipality), Talsi municipality, Valdemārpils rural territory, and elsewhere.

Figure 116. Large cranberry plantation in spring. Photo: A. Priede.

For more information on establishment of large cranberry plantations and experience gained within the LIFE REstore project demo site, see Chapter 6.3.2.

6.2.5. Establishment of highbush blueberry and lowbush blueberry plantations

Ingrīda Krīgere, Dace Siliņa, Inārs Dreimanis, Laimdota Kalniņa

This after-use scenario includes conversion of harvested peatlands into croplands which are used for cultivation of highbush blueberries *Vaccinium corymbosum* (Figure 177) and lowbush blueberries *Vaccinium angustifolium* (Figure 178). Highbush blueberry is a 1.2 to 2 m tall shrub; lowbush blueberry is a low shrub, up to 40–50 cm tall.

Berries of lowbush blueberries are smaller, but sweeter than of highbush blueberries. Both species grow well in open, sunny places. In the following subchapter, both species will be called blueberries.

After reclamation, the purpose of land use is land on which the main economic activity is agriculture; land use type – orchards (real estate code – 0101).

Figure 117. Highbush blueberry. Photo: J. Nusbaums.

Figure 118. Lowbush blueberry. Photo: D. Siliņa.

Conditions when establishment of highbush blueberry and lowbush blueberry plantations is possible

Peat type in the upper layer	raised bog peat
Residual peat layer thickness	> 0.5 m
pH of upper layer peat	4.5–5.0
Peat decomposition degree	poorly to moderately decomposed
Average groundwater table below the surface	well-aerated soils with groundwater table 0.35–0.55 m
Average number of days in a year when the area could be flooded	0
Amount of stumps in peat layer	< 3.0%

Planning and preparation

Several steps should be taken when planning cultivation of highbush or lowbush blueberries in extracted peatlands.

- ✔ Compliance of the planned after-use scenario with spatial planning documents of local municipality must be evaluated.
- ✔ In case if peat extraction (use of mineral resources) is still ongoing, compliance of planned after-use scenario with documents on use of subterranean depths must be evaluated.
- ✔ Reclamation design must be developed and approved in accordance with the procedures set by legislative acts.
- ✔ Construction design of drainage and irrigation systems and other related constructions must be developed and approved in accordance with the procedures set by legislation.
- ✔ If new design on use of subterranean depths is developed or the existing project is modified (in case of establishment of blueberry plantation), preservation of 0.5 m thick residual peat layer must be proposed.

- ✔ The distance between drains remaining after peat extraction must ensure the appropriate soil moisture for blueberries.
- ✔ In cutaway peatlands that have been abandoned long time ago, the vegetation as well as remains of tree trunks and stumps must be removed.
- ✔ Land surface must be levelled; the slope of the surface should not exceed 2%.
- ✔ Reconstruction or modification of the drainage system is necessary, as well as filling in of drains if specified in the reclamation design or in peat extraction project.
- ✔ After removal of vegetation and surface levelling, soil cultivation is necessary.
- ✔ Soil testing and, if necessary, fertilizers should be applied.
- ✔ Technological access roads must be established.
- ✔ Irrigation system must be constructed.
- ✔ Establishment of early warning frost detection system is recommended.

Preparation and maintenance of drainage system; support of water availability

Average groundwater table must be ensured at depth of 0.35–0.55 m below the ground. The possibility of adjusting of groundwater table with drains is necessary. Reconstruction or modification of the drainage system might be necessary depending on the site conditions. The depth of drains should be planned at least 0.5 m, maximum depth up to 1.0 m (Silava 2016). The functioning of drains is essential to ensure the necessary soil moisture and to avoid flooding.

If there are no water bodies in the plantation area, they must be established to supply the necessary amount of water, which is an essential prerequisite for successful cultivation of blueberries.

Surface preparation and soil amelioration

Highbush and lowbush blueberries grow on soils poor in nutrients, but high organic matter content (above 3.5%) is necessary.

The condition of land surface is an essential condition for the establishment of blueberry plantation. Soil surface must be even, without micro-depressions and elevations. If the surface is uneven, smoothing is necessary to a level that surface slope does not exceed 2%. This allows to protect the plants more effectively from frost and to ensure an appropriate moisture regime, which are among the main factors influencing the expected yield. After surface levelling, subsoiling is necessary, at an average depth of 0.4 metres.

If the establishment of blueberry plantations is planned as reclamation measure in areas where peat extraction is not started yet or is ongoing, it is recommended to use peat milling technology as the final stage for peat extraction for at least 2–3 years. This will ensure that land surface will be smooth and additional levelling, milling and other works will not be necessary, thus reducing the cost of site preparation.

Soil agro-chemical tests should be carried out prior to planting. If soil pH value is inappropriate (4.5–5.0) (Apše, Kārkliņš 2013) and soil is deficient in nutrients, soil amelioration is necessary (for example, liming, gypsum application, fertilisation) (LLKIC 2016).

In areas where peat extraction has been discontinued several decades ago, the area is abandoned and not reclaimed, the vegetation including trees and shrubs must be removed, and their roots extracted. If there are stumps in the upper peat layer, they must be removed.

Planting of blueberries

Highbush blueberries are planted in furrows. To create straight and parallel furrows, markings must be placed at both ends and in the middle of field. Furrows are created with a bed shaper, with an elevation of 0.5 m and width of 0.7 metres. The distance between the furrows is three meters. Berry bushes are planted manually. For every plant, a hole is created, in which a plant is placed, and the hole is backfilled. The distance between the berry plants is 1–1.2 m (depending on the variety). Plants must be watered immediately after the planting. It is recommended to use two- or three-year-old bushes. Recommended planting times are spring or autumn.

An average of 2500 seedlings per hectare is necessary. The first harvest is expected in the third year after planting, reaching about 0.6 t per hectare. Later, regularly producing shrubs reach 5–8 t per hectare (on average, 2.5 kg of bush) (ZM 2011). After 15–20 years, the productivity of highbush blueberries gradually decreases. Then, shrubs can be pruned, leaving 20 cm tall canes. Young shoots will develop, which will produce berries in a couple of years. In this way, bushes can grow up to 50–80 years in the same place (Ripa 2003).

For planting of **lowbush blueberries**, it is not necessary to create furrows. Seedlings are planted at a distance of 0.2 m to 0.4 m, 0.6–1.0 m between the rows. For uniform covering of an entire field, the recommended planting distances are 0.3 x 0.6 m or 0.3 x 1.0 metres. After planting, seedlings must be watered. Lowbush blueberries begin to produce in the second or third year, yielding 0.9 t per hectare. Yield of regularly producing shrubs reach 2–5 t per hectare. These berries are grown in cycles of two or three years of production (and mowed after every 2–3 years).

In blueberry plantations, construction of irrigation system is recommended (both frost protection irrigation and drip irrigation). Although its construction costs are high, experience shows that yields can be small and irregular without it. Using irrigation system eases avoiding frost damage (if plantation is watered before frosts, plants can be protected from rapid temperature fluctuations and cell damage, as water absorbs heat) and to withstand prolonged periods of drought. For the construction of irrigation system, a place where to get water must be located nearby. It is preferable that water from plantation is drained to water supply site during the rainfall, and, if necessary, pumped back to plantations using pumps and pipelines. Highbush blueberries can be mulched to control weeds, maintain soil moisture and reduced GHG emissions.

Contribution to climate change mitigation

When considering the cultivation of blueberries in cutaway peatlands, the potential impact on climate change should be evaluated. The impact on GHG emissions was estimated by LIFE REstore project for a 30-year period following the establishment of highbush blueberry plantations, assuming that these measures are implemented in an area where peat extraction has been discontinued recently and vegetation has not yet developed, but the topsoil is formed by raised bog type peat of low fertility. After reclamation, GHG emissions will decrease by 0.1 t CO_2 eq./ha^{-1} year compared to the initial condition. Total GHG emissions from highbush blueberry plantations during the calculation period correspond to 6.2 t CO_2 eq./ha^{-1} year. GHG emission calculations do not include emissions from fertilizers, which, depending on the applied doses, can significantly increase N_2O emissions from the soil. These emissions are accounted in the agricultural sector using a unified calculation method for converting the applied fertilizer amount into direct and indirect N_2O emissions (LIFE REstore project data). For more on GHG emissions, see Chapters 3.1 and 3.2.

Indications of successful reclamation

The area is flat; there is a functioning drainage system. The entire surface of the field is evenly covered by lowbush blueberries; highbush blueberry bushes are established evenly in furrows.

Indications of unsuccessful reclamation

Drainage system is not operating well, or it is not suitable for growing of blueberries. The area is not homogenous.

Advantages

After peat extraction, the area is used for economic activities that raise employment and income. Topsoil is completely covered by berry plants, thus the GHG emissions are reduced.

Disadvantages

GHG emissions are increased if fields are fertilized for higher yields. However, in case of appropriate timing and doses, a significant increase in emissions is not expected.

Possible works and their preliminary costs

Possible necessary works and their preliminary costs are summarized in Chapter 6.2.10.

Experience in Latvia

The cultivation of blueberries in extracted peatlands in Latvia started in early 21st century. Plantations of highbush blueberries (Figures 119, 120) cover larger areas than lowbush blueberries. Highbush blueberries are cultivated in the former peat extraction areas in Līvbērze rural territory (Jelgava municipality), Līgotņu Mire in Burtnieki municipality, and elsewhere. One of the lowbush blueberry plantations is located in Gaujiena rural territory, Ape municipality.

Figure 119. Plantation of highbush blueberries. Photo: D. Siliņa.

Figure 120. Harvesting of highbush blueberries. Photo: D. Siliņa.

In 2016, the total area size of blueberry plantations in Latvia reached 300 hectares. The cultivation of blueberries as a prospective sector is included in the development concept of the fruit-farming. The berry production has a good outlet in Latvia, the European Union and Russia (ZM 2011). For more information on cultivation of highbush blueberries in the LIFE REstore project demo site: see Chapter 6.3.2.

6.2.6. Establishment of paludiculture fields

Laimdota Kalniņa, Ingrīda Krīgere, Ilze Ozola, Inārs Dreimanis, Andis Lazdiņš

The term "paludiculture" is used in a broad sense for any cultivated plantation on periodically flooded or wet peat soils. In a narrower sense, the term is used for plants which can be cultivated and used economically, and which naturally grow on wet peat soils, including mires.

Paludiculture plants are cultivated to promote accumulation of peat, as high water table is maintained in the fields throughout the year, and partially decayed plants contribute to the formation of peat. Plants capture $CO_{2,}$ ensuring the reduction of GHG emissions. Reeds *Phragmites australis*, cattail *Typha* spp., alders *Alnus* spp., *Sphagnum* mosses and other plant species are cultivated, as their biomass can be used as a renewable natural resource. Paludiculture plants can be grown in extracted peatlands with residual fen and transitional mire peat (slightly acidic, neutral or alkaline pH values are suitable for *Typha* spp., *Phragmites australis*, tall sedges *Carex* spp. and other mire plants), as well as in peatlands with residual raised bog peat (for example, *Sphagnum* mosses, sundews *Drosera* spp.) (Joosten et al. 2014; Gaudig et al. 2017).

Figure 121. Reed canary grass Phalaris arundinacea, a plant species used in paludiculture with a broad range of applications (biomass for energy production, fodder, fiber, etc.), suitable for growing on fen peat. Photo: A. Priede.

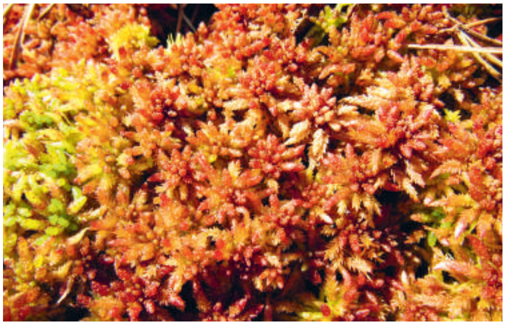

Figure 122. Sphagnum magellanicum and other „hummock species" are cultivated as paludiculture plants on raised bog type peat, and used as growing media, insulation materials and for other purposes. Photo: A. Priede.

The obtained biomass is used in energy and pulp production, in food production and medicine, as forage, timber, growing media, decorative materials, etc. The use of non-wood biomass for pulp production is expected to grow rapidly in Western European countries (Joosten et al. 2014; Ozola 2018). For the production of biomass (biogas, fuel), reed canary grass *Phalaris arundinacea* (Figure 121), common reed *Phragmites australis*, common cattail *Typha latifolia*, narrowleaf cattail *Typha angustifolia* and other species may be used (Ciria et al. 2005; Platače 2013; Schröder et al. 2015; Vos 2015). Reeds can be used for the production of thatching and insulation materials. Cattails and *Sphagnum* mosses (Figure 122) can be used as insulation materials. Fast-growing trees, such as black alders, willows, etc., can also be cultivated for biomass production (Ozola 2018). Several species are used in pharmacy, e.g. sundews *Drosera* spp. (Baranyai, Joosten 2016).

After reclamation, the land use purpose is land under water (codes – 0302, 0303), land use category – land under water, land use type identifier – 052, 053.

Conditions when establishment of paludiculture is possible

Peat type in the upper layer	any type of peat, depending on the requirements of the cultivated species
Residual peat layer thickness	depends on the selected paludiculture species
pH of upper layer peat	depends on the selected paludiculture species
Peat decomposition degree	degree of peat decomposition is of secondary importance, however, moderately decomposed peat (25–30%) is more suitable; well decomposed peat (> 45%) can form a compact layer that can reduce the groundwater impact
Average groundwater table below the surface	depends on the selected paludiculture species
Average number of days in a year when the area could be flooded	depending on the selected species, may sometimes be flooded or flooding is even desirable
Amount of stumps in peat layer	< 3%

Paludiculture plant species must be chosen depending on the hydrological and hydrogeological conditions, including possibility to raise water table to the level suitable for a particular species, as well as taking into account the properties of residual peat layer. The cultivation of paludiculture plants can also be beneficial in areas where water level is maintained by pumping, and excess water is controlled by drainage.

For most of paludiculture plants, a rather thin layer of peat (<0.3 m) is sufficient, therefore this after-use scenario can be implemented in cutaway peatlands where residual peat layer is 0.2 m or less.

The growing conditions of various species are very different. For example, for *Sphagnum* mosses (*Sphagnum fallax*, *S. palustre*, *S. papillosum*, *S. magellanicum*) which are often cultivated in paludiculture, at least 0.1–0.2 thick peat layer of raised bog peat is necessary, but the thickness and type of the peat layer beneath it is not significant. If the cultivation of emergent aquatic plant species, such as reeds, calmus *Acorus calamus*, cattails, is planned in unvegetated peatland, peat layer should not be thicker than 0.1–0.2 m, otherwise it will float up. If the vegetation has already formed, the thickness of the peat layer is not of critical importance.

pH value of the upper layer of peat may vary from acidic to alkaline, depending on the target species. For *Sphagnum* mosses, optimal pH value is 3–4; for cattail, reed, reed canary grass, optimal pH value is 5–7.

The optimal water table is defined by the selected plant species. For calmus and reeds, the site can sometimes be flooded, or the flooding is even desirable. The permissible water level ranges are: -0.5 m to +1.0 m for calmus and reeds; 0.2–0.50 m above the ground for cattails; periodically wet conditions (on average 0–0.2 m below the ground) for reed canary grass and black alder *Alnus glutinosa*. For other species (for example, *Sphagnum*), the water table should be at the level of soil surface, not exceeding +0.1 metres. Flooding is not desirable in *Sphagnum* growing areas. Plantations of some other cultures can be flooded periodically or permanently (such as reeds). For black alder, long-term flooding is not desirable, but it tolerates short-term flooding and to some extent also fluctuating water table. Each species is affected by a variety of critical factors. However, water availability and possibilities to maintain water table are important for all species cultivated in paludicultures (Wichtmann 2016). Important factors are also peat layer thickness, peat type, chemical composition and structure of mineral ground. For *Sphagnum* cultivation, the surface should be as even as possible.

Planning of works

Several steps should be taken if the cultivation of paludiculture plants is planned in an extracted peatland.

- ✔ Before reclamation, the area must be investigated (e.g. peat properties, thickness of residual peat layer, hydrological condition).
- ✔ The compliance of planned reclamation measures with spatial planning documents of local municipality must be evaluated.
- ✔ In case if peat extraction is ongoing, the compliance of the planned after-use scenario with documents of use of subterranean depths must be evaluated.
- ✔ Reclamation design must be developed and approved in accordance with the procedures set by legislation.
- ✔ Construction design of drainage and irrigation systems and other related constructions must be developed and approved in accordance with the procedures set by legislation.
- ✔ Drainage system must be established to ensure optimal water table for the selected species.
- ✔ Remains of tree trunks and stumps must be removed.
- ✔ Field surface must be levelled.
- ✔ If necessary, drainage system must be reconstructed or modified.
- ✔ Paludiculture plants must be sown or planted; the plantation should be continuously managed.

Establishment of paludiculture fields

For planting or sowing of paludiculture plants, the preparation of soil is necessary.

- ✔ If necessary, drainage system must be reconstructed or modified, to ensure optimal water table for the selected plant species.
- ✔ If there are tree stumps in the upper peat layer, they must be removed as this will facilitate both the establishment of plantation and its further management.
- ✔ Field surface must be levelled. It is of particular importance in *Sphagnum* plantations – fields must be as even as possible. In wet depressions, water level is too high for *Sphagnum* mosses, and also on dry elevations the conditions are not suitable for *Sphagnum* (Gaudig et al. 2017).
- ✔ If the establishment of paludiculture is planned as an after-use scenario in areas where peat extraction is not started yet or is ongoing, it is recommended to use peat milling technology as the final stage for peat extraction for at least 2–3 years. This will ensure that land surface will be smooth and additional levelling, milling and other works will not be necessary, thus reducing the cost of site preparation. However, from the experience of peat producers, levelling after the completion of peat extraction is necessary almost every time, to a greater or lesser extent.
- ✔ Infrastructure suitable for management of selected species must be designed and established.

If the planting of *Sphagnum* mosses is planned in a peat extraction site that is abandoned for a long time, it is necessary to cultivate or remove the upper, highly decomposed peat layer.

Hydrological conditions are very important for paludiculture species, as several of them do not tolerate flooding or desiccation, therefore the establishment of an adjustable water supply system is necessary depending on the species or variety. In very wet springs, large proportion of yield may remain unharvested (paludicultures for biomass are mown in spring) because the land manager may be unable to access the area with machinery. Therefore, the well-functioning drainage and irrigation systems must minimize the risk of excess water or severe drop of water table.

After site preparation, selected species can be planted. For planting of *Sphagnum* mosses, the donor material should be preferably collected in sites where establishment of new peat extraction fields is planned, and the living surface of bog (acrotelm) will be removed. To avoid damage, both *Sphagnum* and other donor material should not be obtained in protected nature areas and rewetted peatlands. Seedlings of black alders can be purchased in several tree seedling nurseries in Latvia. Tree nurseries provide also the seeds of paludiculture grasses, such as reed canary grass.

Various methods of planting can be applied. The methods selected depend on the target species. For example, the *Sphagnum* mosses are planted both as sods (so they retain moisture better, but planting requires more manual labour), or can be cut into smaller fragments and spread across the field using agricultural manure spreaders, which allows mechanization of the work to a large extent. Later, both planted or spread *Sphagnum* should be covered with straw to avoid drying out and heat or frost damage (Quinty, Rochefort 2003). For more details on planting of *Sphagnum* mosses: see the LIFE REstore experience in Chapter 6.3.3.

Climate change mitigation

When considering the establishment of paludiculture in the former peat extraction areas, the potential impact on climate change should be evaluated. The impact on the GHG emissions was estimated by LIFE REstore project for a 30-year period, assuming that these measures are implemented in an area where peat extraction has been discontinued recently and vegetation has not yet developed, but the topsoil is formed by raised bog peat that is poor in nutrients, and *Sphagnum* mosses are cultivated. GHG emissions have not been evaluated for the other paludiculture plants that can be potentially grown in Latvia. After establishment of *Sphagnum* paludiculture, GHG emissions will increase by 2 t CO_2 eq./ha^{-1} year compared to the initial condition. Total GHG emissions during the calculation period correspond to 8.2 t CO_2 eq./ha^{-1} year. GHG emission calculations do not include emissions from fertilizers, assuming that they are not applied.

According to the guidelines of the Intergovernmental Panel on Climate Change (IPCC), GHG emission accounting from natural ecosystems is not necessary (see Chapter 3). In this case, paludicultures are considered as natural ecosystems. In the long term, mire vegetation captures carbon and “stores” it in peat.

Indications of successful reclamation

The hydrological regime in the reclaimed area is optimal, indicated by vital stands of cultivated plants. Plants are well rooted, they successfully overwinter and yield the planned harvest.

Indications of unsuccessful reclamation

The establishment of paludiculture can be considered as unsuccessful if the established hydrological and substrate conditions are not suitable for the selected species (the site is too wet or too dry). The failure can be caused also by low quality planting material, for example, by low germination ability, or if large proportion of plants do not establish and die. Also low overwintering success and frost damage indicate on unsuccessful selection of species, variety or improper preparation of the site conditions.

Advantages

Climate change mitigation is an important benefit provided by paludicultures. In conditions of excess moisture, plants develop abundant stands, their roots and stems cover the peat surface. Sod or homogenous *Sphagnum* carpet is being formed. This way, GHG emissions are reduced, as rewetting in drained mires reduce GHG emissions by 10–25 t CO_2/ha^{-1} year, ensuring long-term carbon capture and storage (Greifswald Mire Centre 2018).

The plant cover reduces decomposition and erosion of upper peat layer, prevents the risk of fires in peatlands. In some cases, such sites may be promising ecotourism destinations and can raise employment and income.

Disadvantages

Harvesting is limited by weather conditions. For example, gramineous plants (reed canary grass, reed) used in the energy industry should be almost dry at the time of harvesting. The most appropriate harvesting time is spring, while the soil is frozen, and the moisture content in dead parts of plants is 10–20%. Burning properties are much better in spring than in autumn, because in autumn the moisture content is higher. In years when the spring is very rainy, the amount of energy obtained can be much lower.

The cultivation of paludiculture plants is a new after-use scenario, therefore there might not be sufficient experience accumulated and available for land managers.

Possible works and their preliminary costs

Possible necessary works and their preliminary costs are summarized in Chapter 6.2.10.

Experience acquired

The cultivation of paludiculture plants in extracted peatlands is a relatively new form of land use worldwide (Joosten et al. 2014). At present, more experience on paludicultures is acquired in Germany, where reed canary grass, cattails, reed, Sphagnum are cultivated (Korhonen 2008; Joosten et al. 2014; Greifswald Mire Centre 2018). Quite extensive research and popularization of this type of land use is carried out by Greifswald Mire Centre in Germany.

There is very little experience in cultivation of paludiculture species in Latvia. For example, Sphagnum plantation was established in Mālpils municipality on fen type peat. The first harvest is planned in 2019.

6.2.7. Afforestation

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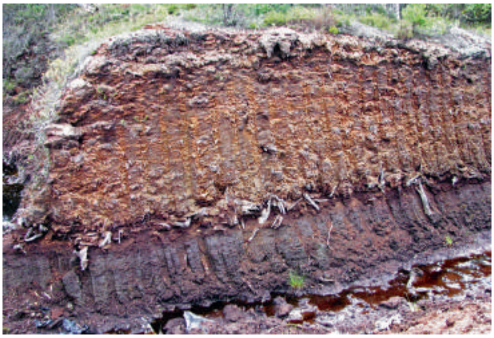

Figure 123. Cross-section of peat layers in Seda Mire. The lower (dark) layer is composed of fen peat. Above it, there is a 2800–3000 years old layer of wood peat (stumps), covered by slightly decomposed raised bog *Sphagnum* peat. Photo: L. Kalniņa.

It is important to foster and develop the production of high-value products and services through sustainable use of extracted peatlands. After cessation of peat extraction, layers of unused peat often remain on site (Figure 123). If a layer of raised bog peat has remained, the possible further uses include rehabilitation to re-create mire conditions, cultivation of Sphagnum mosses, agriculture or forestry.

If peat extraction has exposed the fen peat or transitional mire peat layers or the mineral ground, the conditions are not suitable for restoring a bog vegetation. However, it is possible to continue using land and gaining economic benefits by establishing woodland or by cultivating crops which are tolerant to harsh growth conditions. One of the types of crop production is perennial plantations of trees, including short-rotation woody crops, i.e. cultivation of "permanent crops" – trees as "short rotation coppice" – **plantings of woody species** or establishment of plantation forests (Figure 124).

Agricultural land – crop production	Forest land – forestry	
Plantings of woody species – perennial plantations (except for ornamental trees, orchards and tree nurseries), which are established in agricultural lands for specific purposes and whose maximum production cycle is up to 15 years, after which cultivation of the crop is re-initiated or the land is used for other agricultural crops.	**Forest –** an ecosystem at all stages of its development, where the main producer of organic matter is trees, with a height of at least five metres, whose current or potential crown projection is at least 20% of the area of woodland. There is defined felling age that is determined by age or diameter. Minimum number of trees planted per hectare: *Pinus sylvestris* – 3000; *Quercus robur*, *Fraxinus excelsior*, *Ulmus laevis*, *U. glabra*, *Acer platanoides*, *Fagus sylvatica*, *Carpinus betulus* – 1500; other species – 2000 trees per hectare.	**Plantation forests** – planted woodlands for specific purpose. Felling age is not defined. The minimum number of trees planted per hectare: *Pinus sylvestris* – 1000, *Picea abies*, *Quercus robur*, *Fraxinus excelsior*, *Ulmus laevis*, *U. glabra*, *Acer platanoides*, *Fagus sylvatica*, *Carpinus betulus* – 500; other species – 800.
Short-rotation coppice species or genus (with land use codes)[55]: *Populus* spp. (644); *Salix* spp. (645); *Alnus incana* (646).	**Tree species and genus**: *Pinus sylvestris*, *Picea abies*, *Betula pendula*, *Betula pubescens*, *Populus tremula*, *Alnus glutinosa*, *Fraxinus excelsior*, *Quercus robur*, *Tilia cordata*, *Acer platanoides*, *Ulmus glabra*, *Ulmus laevis*, *Alnus incana*, *Carpinus betulus*, *Fagus sylvatica*, *Cerasus avium*, *Salix* spp., *Sorbus aucuparia*, *Larix* spp., *Populus* spp., *Quercus rubra*, *Alnus* spp.	

Figure 124. Tree species suitable for planting in different types of land use and management systems.

55 Law "On Agriculture and Rural Development".

In Latvia, plantations of woody species can be established as agricultural crops with rotation cycle of up to 15 years (Figure 124). If short-rotation coppice plantations are managed in rotation cycle of five years and they are established in undrained areas, the plantation may be applied for a single area payment scheme.

Tree species suitable for short-rotation coppices can be grown both in agricultural and in forest land. For the establishment of woodland, planting material suitable for forest conditions should be selected, because not all clones used in tree plantations are suitable and accepted in national regulations for planting a forest.

In the following subchapter, only establishment of forest and forest plantations are analysed which, in terms of Forest Law, is "a set of measures for forest establishment in land which is not registered as forest in the State Real Estate Cadastre Information System".

Conditions when afforestation is possible

Peat type in the upper layer	not important
Residual peat layer thickness	depends on tree species (peat layer thicker than 30 cm is suitable for *Pinus sylvestris*, *Betula* spp., *Alnus* spp., *Salix* spp., *Populus* spp.)
pH of upper layer peat	> 4 (liming is necessary if pH value is lower; dose depends on tree species)
Peat decomposition degree	≥ 0.35 m
Average groundwater table below the surface	up to 5 days outside the vegetation season; 1–3 days during the vegetation season
Average number of days in a year when the area could be flooded	not important if the movement of machinery necessary for management is not encumbered

The most important conditions for successful afforestation are: soil pH; content of micro- and macro-elements; aeration (no stagnant water; oxygen uptake by tree roots is possible). Also soil carrying capacity, affected by the thickness and humidity of the peat layer, is important. Soil bearing capacity is related to the planned timing of timber harvesting and choice of suitable equipment.

Planning of works

Compliance with legislation and spatial plans

Several aspects have to be considered before deciding on afforestation as an after-use scenario of cutaway peatland and prior to selection of the site for afforestation, means of afforestation (natural afforestation or planting) and legal status (forest or plantation forest).

- ✔ The compliance of planned reclamation with spatial planning documents of local municipality must be evaluated.
- ✔ In case if peat extraction still continues, compliance of the planned after-use scenario with documents of use of subterranean depths must be evaluated.
- ✔ Reclamation design must be developed and approved in accordance with the procedures set by legislation.
- ✔ If reclamation is planned in a cutaway peatland that has been abandoned without reclamation for a long time, the necessity for environmental impact assessment or initial environmental assessments according to legislative acts must be clarified (environmental impact assessment is necessary if afforested area is larger than 50 ha).
- ✔ The necessary conditions for the reconstruction of drainage system must be evaluated (status, legal and site-related restrictions, ownership, etc.).

In cutaway peatlands that have been abandoned without reclamation for a long time, experts on species and habitat conservation must be involved already in the planning stage, before taking decision about afforestation as the appropriate reclamation type. The experts should evaluate the following aspects:

- ✔ presence of protected species characteristic to forests and indication of natural forest recovery;
- ✔ indications of natural mire recovery (potentially valuable mire habitat);
- ✔ spontaneous recovery of bog woodland (*Sphagnosa* forest type); in this case, the number of forest trees should be increased, but soil preparation and amelioration are not necessary.

Planning of technical works

Figure 125. Spreading of ash. Photo: G. Spalva.

The drainage system must be reconstructed. Functioning collection ditches must be maintained during the entire growth period of woodland. The establishment and maintenance of drainage system should prevent the risk of prolonged flooding.

Site surface preparation works are not necessary after peat extraction with milling. In sites where peat extraction was discontinued when reaching the stump layer, stumps must be removed by establishing corridors which will be necessary for movement of machinery. Removal of stumps in the entire area is necessary only in case if application of fertilizers in topsoil is encumbered by stem layer.

In raised bog and transitional mire peat soils, potassium and phosphorus deficiency is very common. In raised bog peat soils, lack of nutrients affects young trees. Here, establishment of woodlands without additional input of nutrients is usually problematic. On fen peat soils and transitional mire peat soils, lack of nutrients is usually observed in medium-aged forests. In case if the ground vegetation is not developing well and trees do not spontaneously establish, soil amelioration is necessary.

In order to improve growing conditions (raising of soil peat pH and supplementing the soils with plant nutrients), wood ash may be used (3–6 t per ha), as it has the properties of liming material and contains all nutrients which are necessary for tree growth and which may be deficient in the former peat extraction areas (Figure 125). In order to avoid use of ash that may contain harmful substances, chemical analysis should be performed prior to application or ash should be purchased from producers listed in the database of the State Plant Protection Service (www.vaad.gov.lv).

In cutaway peatlands, the conditions are suitable for tree species which are tolerant to varying environmental conditions, for example, birches *Betula* spp. They grow well after planting, and they are also naturally able to colonize such areas (Fay, Lavoie 2009). Both *Betula pendula* and *B. pubescens* are important species for the afforestation of cutaway peatlands as they quickly colonize the areas and can be valuable for (1) timber harvesting, (2) protecting other trees from frost damage if shade tolerant species are planted below canopy layer of birches and (3) they can increase biodiversity in admixture of conifers (Renou, Farrell 2004; Hytönen, Aro 2012).

In some literature sources (e.g. Renou-Wilson et al. 2008), the ability of black alders *Alnus glutinosa* to reach high productivity in acidic peat soils (if damage caused by animals is prevented) is highly valued. It is important to note that periodic flooding is well tolerated by black alders, but only if the water is not stagnant (Renou-Wilson et al. 2008; Hytönen, Saarsalmi 2009). Also the grey alders *Alnus incana* are often recognised as valuable pioneer-species for afforestation of cutaway peatlands (Renou-Wilson et al. 2008). For willows *Salix* spp. and poplars *Populus* spp., soil pH value is very important, therefore soil preparation, fertilization and liming may be necessary for these species (Hytönen 1995; Hytönen, Aro 2012).

Although growing slowly at the early stage after planting, Scots pine *Pinus sylvestris* is species which fits best for afforestation of cutaway peatlands. It grows well in areas with groundwater table below 30 cm (Mangalis 2004). Thus, the desirable groundwater table for afforestation is below 0.35 metres. If residual peat thickness is 10–30 cm and it is possible to ensure groundwater table below 1 m, conditions are suitable also for spruce *Picea abies*, larch *Larix decidua*, birches and aspens (Mangalis 2004).

Practical works

Preparation and maintenance of drainage system; surface preparation

Surface levelling is necessary in the former peat quarries and block-cut areas. Peat extraction methods used nowadays allow leaving an even field after the cessation of extraction. In cutaway peatlands abandoned for long time, vegetation cover must be removed. Possibly, also removal of old vehicles, building materials and other waste, as well as levelling of ditch berms may be necessary.

It is recommended to preserve former technological roads in case if establishment of new drainage system or the construction of ditches or reconstruction of subsurface drainage system is planned. Roads will be useful for vehicles to approach the area and to carry out management work.

Ploughing, cultivation, gathering of stumps and other tree remains are necessary only if application of fertilizers or liming is planned.

Site preparation for planting of trees

After the soil amelioration works (described in the previous sections), rows of trees to be planted are marked (Figure 126). The arrangement of the tree rows is planned according to the number of trees, the options for moving the machinery and the width of the work equipment. The distance between the rows must be suitable for tending in the next years. The distance between trees in the row is calculated by dividing the required number of trees (depending on species) (Figure 124) by the number of rows. Planted trees must be distributed evenly. The trees are planted in rows no closer than 1.5 m to each other.

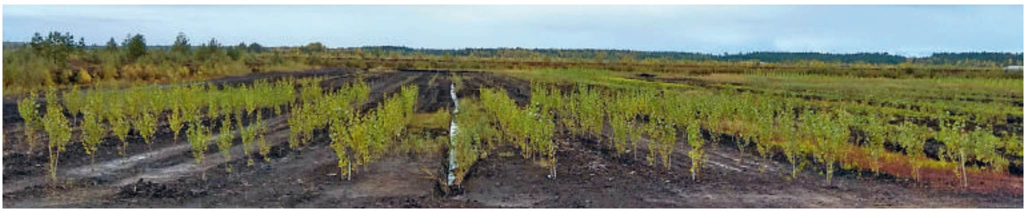

Figure 126. Trees planted in rows. Photo: D. Lazdiņa.

Fertilization

For soil amelioration in the former peat extraction fields, municipal or energy production by-products can be used, such as sewage sludge, wood ash, digestate, as well as mineral fertilizers. The soil liming is necessary if the selected fertilizer does not have soil acidity-reducing properties, or if peat is acidic (pH < 3.0). Application of wood ash in cutaway peatlands can effectively improve tree growth, and the effect of fertilization can last up to 50 years (Houtari et al. 2011).

In sample plots established by the Latvian State Forest Research Institute "Silava", use of sewage sludge as a principal fertilizer ensured successful tree growth for 13 years after fertilization, while the application of similar dose of phosphorus principal fertilizer with mineral fertilizers stimulated the development of woodland only for five years after the fertilizer application (Bebre, Lazdiņa 2017). In sample plots where trees were fertilized using wood ash, trees were vital after three years, while trees planted in control plots (without ash application) showed signs of nutrient deficiency.

Tree planting

Trees can be planted with hand tools or mechanically. Planting method depends on type of planting material. For container seedlings, planting tubes can be used. Bare-root plants with improved root system can be planted only with shovel or with planting spear. In peatland where soil is improved and cultivated, small-sized bare root plants can be planted not only with shovel but also with planting machine.

Seedlings should be stored in shade during planting. At least 2–3 cm thick layer of peat should cover root collar and substrate. Roots of seedling must be placed vertically in the planting hole and should not be left above the soil surface. If the roots are very long, they can be shortened by cutting, forming a 20–15 cm long root system. Roots should not be shortened by pulling them off, as it damages the root at its full length. The long roots should not be wrapped around each other – it creates an additional stress for the tree and facilitates creation of unstable root system.

Management

Not only the growth of trees, but also weeds are stimulated by soil amelioration. Soon after the fertilization, agrotechnical measures (improvement of insolation) will be necessary, as well as mowing of herbaceous vegetation if tree growth is suppressed by ground vegetation. Agrotechnical measures should be planned for several consecutive years (Figure 127). Cleaning and tending can be carried out mechanically, if it has been planned when planting the trees, by choosing the distance among the tree rows suitable for movement of vehicles.

Figure 127. Plantation of pines in harvested peatland; removal of weeds in the third year after planting. Photo: D. Lazdiņa.

During the first five years after planting, the trees should be protected against ungulate browsing. This can be done by treating the trees with repellents *Cervacol* or *Triko*, or using protection tubes. In larger plantations, it is more cost-efficient to fence the area than to protect each individual tree.

The area should be monitored to see if there is no beaver activity in ditches that could affected the area by raising the water table.

Contribution to climate change mitigation

Afforestation reduces GHG emissions from cutaway peatlands (Wilson et al. 2009). In afforested former peat extraction fields, peat decomposition does not take place or is slower than in harvested peatlands that are used for agriculture. Therefore, afforestation is considered as a good option for areas affected by peat extraction whenever possible (Strack (ed.) 2008).

After successful afforestation, soil amelioration (fertilization, liming, cultivation) should be repeated after several decades (after thinning and regenerative harvesting). This reduces soil temperature and microbial activity, thus slowing down the rate of peat decomposition and reducing CO_2 and N_2O emissions (Mäkiranta et al. 2007).

In forests on drained organic soils, CO_2 emissions created by decomposition of raised bog and transitional mire peat are compensated by CO_2 capture in wood biomass, ground floor, ground vegetation, and dead wood. However, in fertile fen peat soils, GHG emissions can be larger than CO_2 captures also after the afforestation (Mäkiranta et al. 2007). The amount of carbon stored in biomass is directly proportional to the growth of trees – the faster the biomass is accumulated, the more carbon is stored in woodland (IPCC 2006), therefore, development of productive woodland must be supported by management measures. Non-productive woodland in cutaway peatland will not contribute to climate change mitigation.

Indications of successful reclamation

Afforestation is successful if the following conditions are met and the following indications are observed:

- ✔ the planned forest drainage system is constructed and well operating;
- ✔ drainage system is well functioning; drained, well-aerated soil layer is at least 0.35 m thick;
- ✔ after a year, the number of established trees corresponds to the planned number of trees; trees cover the entire area evenly;
- ✔ the number of perished trees does not exceed 10% per year during the first two years after planting;
- ✔ the woodland is not significantly damaged by wild animals;
- ✔ ground vegetation develops in woodland; weed species are being replaced by forest species. Spontaneous establishment of trees takes place.

Indications of unsuccessful reclamation

The drainage system is poorly functioning (reasons may include beaver activity). Consequently, the topsoil is water-logged in large proportion of the area. This is indicated by stagnant water in ditches, sometimes overgrown with algae.

The trees are unhealthy; needles or leaves are discoloured, treetops are withered. Ground vegetation is not developed, or poorly developed and sparse.

Expected economic benefits and costs

Afforestation as an after-use scenario requires financial investments – purchase of seeds or seedlings, tending, and thinning.

If pH value of the residual peat is low, soil liming is necessary. For this purpose, wood ash is suitable as it contains micro- and macro-elements necessary for plant growth, which are usually deficient in peatlands after cessation of peat extraction. The cost of planting material can be reduced if establishment of plantation forest is planned or if spontaneous establishment of trees is encouraged.

For establishment of a plantation forest, the minimum number of trees to be planted is lower than in forests: pines should be planted by 2000 trees less per hectare, spruces, birches, black and grey alders by 1200 trees less per hectare. For plantation forest, there is no fixed age of felling. In this way, it is possible to reduce the probability that trees may be exposed to various risks before felling (wind-throws, fires, insect outbreaks). Invested financial resources will be compensated sooner as tree rotation cycles are shorter.

Spontaneous establishment of forest can be promoted by soil amelioration. Establishment of birches and pines from seeds carried by wind or animals from the neighbouring woodlands can be encouraged. If choosing spontaneous afforestation scenario, the other above-mentioned activities (soil amelioration, drainage, etc.) are still necessary. If timber harvest is the main economic purpose, it must be taken into account that the stem quality and productivity will be 15 to 20% lower than by using selected reproductive material.

Soil fertilization is necessary not only before, but also after planting of trees, and this will create additional costs. Nutrients are applied after the commercial felling. Also reconstruction of drainage system might be necessary if it has been improperly managed. In unreclaimed areas abandoned for a long time, reconstruction of drainage system is necessary before afforestation.

Both wood and non-wood forest products may be obtained during the development of woodland.

- ✔ Both after planting of trees or spontaneous tree establishment, the established ground vegetation contains species which produce nectar and pollen for pollinating species throughout the growing season.
- ✔ Biomass (with or without leaves) can be obtained when carrying out thinning. It can be used for energy production, in pharmaceuticals, cosmetics, as raw material for nutritional supplements.
- ✔ Hunting and other forms of recreation can be organized in afforested peat extraction areas.

The site manager must be aware of the risk that woodlands in cutaway peatlands may not reach the highest productivity. Due to growing in harsh conditions, the proportion of trees with bended trunks, cavities, and other stem disturbances is larger. If trees grow in substrates with a high groundwater table, they form a shallow root system that increases the risk of wind-throws, decay, and weaker resistance to pathogens.

Possible works and their preliminary costs

Possible necessary works and their preliminary costs are summarized in Chapter 6.2.10.

Experience in Latvia and other countries

In Latvia, extensive research on afforestation has been carried out in Seda Mire where various tree species were planted in 1964 both on shallow and deep peat soils – birches, pine, spruce, aspen, and larch. Most of these woodlands have survived until nowadays. At 30-years age, their growth was assessed (Mangalis 2004).

There are highly productive, healthy plantations of Scots pine with timber volume 144 m^3/ha. Growth was not influenced by the thickness of peat layer. For Norway spruce (planted in sites with 30–35 cm thick peat layer) the timber volume is 6% smaller than timber volume of pines, and the spruce plantation suffers from spring frosts. The root system of spruce is shallow, and there is a risk of wind-throw. Birches develop productive, sustainable forest stands with a timber volume of 195 m^3/ha. European larch grows poorly, especially in places where peat thickness exceeds 25 centimetres. As suggested by results of scientific studies and practical experience, pine and birches are the most suitable tree species for afforestation in former peat milling fields (Mangalis 2004).

Research on the impact of peatland afforestation on climate change had not been carried out in Latvia before the LIFE REstore project. Also elsewhere in the world, there is a lack of long-term studies on impact of afforestation on GHG emissions. The most extensive research on peatland management, including climate change mitigation, is carried out in Finland (Hytönen 1995; Hytönen, Kaunisto 1999; Aro 2000; Mäkiranta et al. 2007; Hytönen, Saarsalmi 2009; Huotari et al. 2011, 2008; Jylhä et al. 2015) and Ireland (Renou et al. 2007; Renou-Wilson et al. 2008, 2010; Wilson et al. 2009; Bord na Móna 2011; Renou-Wilson 2011).

Studies on the impact of mineral fertilizers and wood ash on spontaneous tree establishment in cutaway peatlands in Latvia have been carried out only in recent years. In sample plots fertilised with wood ash in 2008, spontaneous establishment of birches, pines, spruces and aspens was observed. In research plots treated with mineral fertilisers, tree species characteristic for alkaline soils, such as common aspen, did not establish (Bebre, Lazdiņa 2014). Similar results were obtained during the LIFE REstore afforestation experiment (see Chapter 6.3.1) – spontaneous afforestation was promoted by application of wood ash (Figures 128, 129) (Neimane et al. 2019).

Figure 128. Development of ground vegetation after fertilization with wood ash in LIFE REstore demo site in Kaigu Mire, August 2017 (trees were planted in spring of the same year). Photo: D. Lazdiņa.

Figure 129. Spontaneous afforestation with aspens, birches and willows in the second year after the application of fertilizer. Photo: D. Lazdiņa.

Studies on use of sewage sludge in reclamation of cutaway peatlands in Latvia began in 2005. In Medema Mire, the former peat extraction fields were fertilised with sewage sludge (10 t of dry matter per hectare, using wood ash and mineral fertilizer). Later, birches, pines and black alders were planted, and also spontaneous establishment of birches was promoted (Figure 130) (Lazdina et al. 2006). Nine years after planting, it can be concluded that:

Figure 130. The former peat extraction area with birch stand: on left – planted, on right – spontaneously established. Photo: D. Lazdiņa.

- ✔ woodlands fertilized with organic fertilizer – sewage sludge – reached significantly higher productivity than woodlands fertilized with mineral fertilizers or wood ash;
- ✔ sewage sludge has a much longer lasting effect than mineral fertilizers and also contributes to the formation of vigorous, diverse ground vegetation;
- ✔ Scots pine is the most suitable tree species for afforestation of cutaway peatlands in Latvia; it reached the largest timber volume in areas fertilized with sewage sludge;
- ✔ birches are the most promising tree species for spontaneous afforestation (Bebre et al. 2015).

The studies show that sewage sludge has a relatively low ability to raise soil pH value, therefore in acidic soils it should be used in combination with liming materials such as wood ash or dolomite sand (Lazdiņa et al. 2011).

6.2.8. Creation of water bodies

Ingrīda Krīgere, Inārs Dreimanis, Laimdota Kalniņa, Andis Lazdiņš, Dace Ozola

This after-use scenario includes establishment of artificial water bodies in cutaway peatlands. The creation of water bodies (ponds, pond complexes) is the most suitable after-use scenario in areas where the peatland has developed by overgrowing of lakes, or areas which during peat extraction were maintained by pumping out the excess water (Šnore 2013). This means that peat extraction area will fill up with water when pumping out will be ceased. After peat extraction, the area is filled up with water and used for pond farming, for biodiversity conservation as waterbird habitat, or for recreation. In the long run, if no proper management measures (for example, reed mowing) are taken, overgrowing of water body and development of vegetation characteristic for fens is expected.

After implementation of this after-use scenario, the land use purpose is land under water objects (codes – 0302, 0303); land use category: land under water objects. Identification of land use purpose – codes 052, 053.

Conditions when creation of water body is possible

Peat type in the upper layer	partly limiting factor
Residual peat layer thickness	0.1–0.15 m
pH of upper layer peat	not important
Peat decomposition degree	well decomposed fen peat
Average groundwater table below the peat surface	the highest possible
Average number of days in a year when the area is flooded	permanently
Sediments in mire bottom	limiting factor
Amount of stumps in peat layer	not important

Creation of water bodies is suitable as an after-use scenario in areas where peat layer is extracted and the mineral ground is exposed. Then, the degree of water mineralization will be higher, pH value will be neutral or alkaline, providing better conditions for aquatic macrophytes and fish.

The type of the upper peat layer is a partly limiting factor for creation of water body in an extracted peatland. If the residual peat layer consists of raised bog peat, it indicates that mire was developed by paludification of mineral sediments, and there is insufficient groundwater supply. The amount of precipitation will not be sufficient to fill up the reservoir. However, if the water body is planned only as a waterbird habitat, its partial overgrowth is desirable.

Also the composition of the mineral sediments of mire bottom is important for establishment of water bodies. If sediments in the mineral ground are highly or moderately permeable (sand, clay loam), the creation of water body will be complicated or even impossible. Perhaps in such case this after-use scenario can be implemented if peat layer of a certain thickness is located above the highly or moderately permeable mineral ground, not allowing the discharge of water. The recommended degree of peat decomposition is 45–50% or higher. If mire bottom is composed of moderately permeable sediments (fine silt, loam) or poorly permeable (clay), water will stay here, and water body establishment is possible.

Hydrological and hydrogeological conditions (the type of water supply) are also essential for the establishment of the water body. It is necessary to assess the water sources: precipitation, surface water (watercourses, ditches) or groundwater, and what is the ratio of these sources (Korhonen 2008).

The following hydrological conditions are suitable for creation of water body:

- ✔ there is a sufficient groundwater supply in relief depressions, and the groundwater table is high; such conditions will ensure a stable water level in the water body;
- ✔ the site is bordering with watercourse, where the average annual water level is higher than the surface of area of the planned water body.

Hydrological conditions are not suitable for creating a water body if the area is fed primarily by precipitation, as it cannot ensure the necessary amount of water throughout the year.

It is recommended to carry out hydrotechnical calculations or hydrogeological modelling that allows estimating the water dynamics in the particular area. This allows planning the details, e.g. the proportion of the area that could be successfully filled up with water, the depth of the planned water body, and potential annual water table fluctuations.

Planning of works

A number of conditions should be taken into account when designing a water body in cutaway peatland.

- ✔ Compliance of the planned reclamation measures with spatial planning documents of local municipality must be evaluated.
- ✔ In case if peat extraction is ongoing, compliance of the planned after-use scenario with documents of use of subterranean depths must be evaluated.
- ✔ If creation of water body is planned in a cutaway peatland that has been abandoned a long time ago, it must be clarified if environmental impact assessment or initial environmental impact assessment are necessary in accordance with legislation.
- ✔ Information of previous geological surveys must be evaluated, as well as geological and hydrogeological conditions of the particular site.
- ✔ The influence of planned reclamation measures on the use of adjacent areas must be evaluated.
- ✔ Pond or a pond system is an artificially created water body that is classified as a hydrotechnical structure in accordance to legislation, therefore the legislative acts concerning drainage systems and hydrotechnical structures must be followed.
- ✔ Construction project must be developed and approved in accordance to regulations and laws regulating the construction of drainage systems and hydrotechnical structures.
- ✔ Before filling up with water, the area must be completely cleared from vegetation and stumps; existing constructions and systems must be dismantled.
- ✔ Elements of drainage system and hydrotechnical structures must be modified or eliminated according to the construction project.
- ✔ The stability of banks must be evaluated; bank erosion must be prevented, if necessary.

Creation of water bodies

In peatland without vegetation, the upper peat layer must be removed, leaving as little as possible (no more than 0.1–0.15 m of peat), as the residual peat layer can float up (Šnore 2013). Creation of water bodies is a suitable after-use scenario in areas where the whole peat layer has been extracted down to the mineral ground. In this case the water will have a higher degree of mineralization, high pH value, and other hydrochemical properties that are not typical in dystrophic bog water (Kļaviņš et al.

2011). However, this type of peat extraction areas have been abandoned relatively long time ago, because in the last decades at least 0.3 m layer of peat has been left in the extraction sites, and usually more (0.5–0.6 m) (Šnore 2013).

In accordance to technical solutions specified in the construction project, complete dismantling of technological roads, culverts and other elements of peat extraction drainage system is necessary before filling with water; hydrotechnical structures must be dismantled of modified. Water body and related hydrotechnical structures must be established in accordance to the construction project.

In order to prevent bank erosion caused by waves and ice, shores must be gentle sloping. Bank erosion can also be minimized if spontaneous development of vegetation is promoted before inundation. Gentle-sloping banks are preferable also due to safety reasons.

When adjusting the water level in the water body, the stability and further modification of banks must be considered. Stumps must be removed from the bottom of the water body. Bank reinforcement and reduction of shallow water zone (if the water depth does not exceed 0.5 m) might be necessary.

Commonly the mineral ground is uneven, therefore it is never possible to extract the entire peat deposit (which would be the desirable condition for artificial water bodies in extracted peatlands). A possible solution is ploughing up the peat layer, mixing the residual peat layer with mineral ground, and leaving the site for several years. This will accelerate peat decomposition and establishment of vegetation, thus the risk of peat floating up will be reduced.

If creation of water bodies for recreation is planned, especially for fish farming and angling, the planned water bodies should be at least 1.5–2.0 m deep, with some deeper depressions. Also from this point of view, it is advisable to extract peat to the mineral ground, because the mineral-rich groundwater will enrich water with inorganic ions (calcium, hydrogen carbonates, etc.), enhancing the conditions for aquatic macrophytes and fish, and also the floating up of residual peat layer will be prevented. Aquatic macrophytes provide food supply for fish, living environment for algae, invertebrates, fish and water birds (Caffrey 1998). The thickness of optimal residual peat layer should be determined by hydrotechnical calculations.

If the site will mainly be used as a habitat for water birds, the reservoir does not have to be deep, and there are no special requirements for water quality. A mosaic of open water and emergent vegetation (most often reeds and high sedges) may be suitable for water birds. Ideally, if islets for bird breeding are preserved or created (Figure 131) (Šnore 2013). In order to promote biodiversity, it is recommended to establish various depths and irregular coastline. This will increase the diversity of ecological niches and thereby species.

Figure 131. Water body with gentle sloping banks and a mosaic of islets – a habitat suitable for water birds. Photo: A. Priede.

If the purpose of creating the water body is biodiversity restoration, or the extraction of residual peat layer is economically unprofitable or impossible, the residual peat layer may be inundated. Then the bottom of water body will consist of sediments rich in organic substances, which will enhance overgrowing of water body and, in long term, development of peat-forming vegetation and accumulation of peat. If there is sapropel below the peat, peat may be extracted down to the sapropel sediments, and former peat extraction field should not be cultivated or ploughed up.

If hydrotechnical calculations show that the desired water level cannot be achieved, other after-use scenarios or their combinations must be considered as more appropriate.

Contribution to climate change mitigation

When considering creation of water bodies in cutaway peatlands, the potential impact on climate change should also be evaluated. The impact of the respective after-use scenario on the GHG emissions was estimated by LIFE REstore project for a 30-year period, assuming that the water body is created in an area where sufficiently thick layer of fen or transitional mire peat is preserved, and GHG emissions correspond to average values of a restored former peat extraction area after rehabilitation. For comparison, the preservation of current situation in peat extraction site was used. After the establishment of water body, GHG emissions will increase by 7.4 t CO_2 eq./ha^{-1} year compared to the initial condition. Total GHG emissions during the calculation period correspond to 13.6 t CO_2 eq./ha^{-1} year (LIFE REstore project data).

Indications of successful reclamation

Creation of water body is successful if: (1) requirements and technical solutions specified in the project on use of subterranean depths or in the reclamation design are implemented in the entire area of the planned water body; (2) the area to be reclaimed or part of it is fully covered with water throughout the year, achieving the planned water level.

If the purpose of after-use is to restore biodiversity or recreation, successful reclamation is indicated by breeding of various waterbird species and presence of diverse aquatic macrophyte vegetation.

Indications of unsuccessful reclamation

Reclamation is considered to be unsuccessful if: (1) the area is not covered with water at the planned depth throughout the year; (2) the owner or legal possessor of the site must make additional hydrotechnical calculations and actions to raise the water level; (3) unexpected runoff is observed and additional measures to prevent it must be taken; (4) water level cannot be maintained permanently and creation of water body fails, thus another after-use scenario must be introduced.

Advantages

Creation of water bodies bring economic benefits: the site may be used for other purposes, for example, for fisheries of recreation. In most cases, biodiversity benefits from this type of reclamation. Water body itself and vegetation along the banks and on islets provide habitats for waterbirds and stopover site for migratory birds. Diversity of other species may be high. The area may be attractive also for recreation (angling, waterfowl hunting, wildlife watching). Depending on the depth of the water, its chemical composition and other factors, mire ecosystem and its functions may be able to recover during a longer period of time.

Disadvantages

The peat layer covered with water releases carbon dioxide and methane into the atmosphere, therefore its preservation is not desirable. Brown-water ponds are less attractive for recreation. The high content of organic matter and humic substances create unfavourable conditions for fish and other species due to insufficient food resources and other unsuitable conditions. This may directly affect the diversity and abundance of fish and other species, and hence the angling opportunities.

Possible works and their preliminary costs

Possible works to be carried out and their preliminary costs are summarized in Chapter 6.2.10.

Experience in Latvia

In Latvia, there are several cutaway peatlands or individual peat extraction fields within larger peat extraction areas that have been used for creation of water bodies. This is more often done in protected nature areas or in areas where water pumping stations (e.g. Seda Mire) have been used for peat extraction. Water bodies in Seda Mire are mainly used for angling, whereas large proportion of Seda Mire Nature Reserve, nowadays covered with pond system (average depth of ponds is 0.7–1.4 m), serves as an important bird area (Anon. 2006).

Figure 132. Ponds in Kačori Mire. Photo: J. Nusbaums.

Figure 133. Ponds in Lādzēni Mire, a suitable area for recreation. Photo: J. Nusbaums.

Water bodies created in Kačori (Figure 132) and Lādzēni Mires (Figure 133) are used as a recreational area for angling and hunting.

6.2.9. Rewetting (re-creating mire conditions)

Ingrīda Krīgere, Laimdota Kalniņa, Inārs Dreimanis, Andis Lazdiņš, Māra Pakalne

Rewetting (defined as *renaturalizācija* in national legislation) is an after-use scenario for re-creating mire conditions and supporting establishment of peat-forming vegetation. Pristine mires or parts of them are destroyed in result of peat extraction. However, in most of peat extraction areas it is possible to re-create suitable environmental, and most importantly, moisture conditions for recovery of peat-forming vegetation. In some cases, under favourable climatic and hydrological conditions, mire plants can establish, and the mire ecosystem can self-regenerate without deliberate measures, most often due to poor functioning or non-functioning ditches (Nusbaums 2008; Nusbaums, Silamiķele 2012; Cupruns et al. 2013).

The main purpose of rewetting is re-creation of mire ecosystem functions, as well as restoring hydrological regime typical for mires, supporting establishment of peat-forming vegetation and biodiversity (Quinty, Rochefort 2003; Priede 2017). Each peatland and each area to be reclaimed is unique. Careful research and individual approach in each site are necessary for successful implementation of this after-use scenario. Each individual area differs from one another by climatic, hydrologic and hydrogeologic conditions, peat layer thickness and properties, topography of peatland and the surrounding areas (Schouten 2002; Schumann, Joosten 2008).

This type of peatland rehabilitation can be implemented in two ways:

- ✔ by restoring the hydrological conditions necessary for peat-forming vegetation and expecting that the vegetation and, consequently, peat formation will recover itself (see also Chapter 4.4);
- ✔ by restoring the hydrological conditions and reintroducing peat-forming vegetation – mire plant species, in order to promote and accelerate recovery of mire and peatland ecosystem functions (see also Chapter 6.3.3).

Rehabilitation of peatland ecosystem is a priority after-use scenario in protected nature areas or areas bordering with mires or other wetland types located within protected nature areas.

After rehabilitation, the purpose of land use is forestry land (forestry is the main economic activity), code – 0201.

Conditions when rewetting is possible

Peat type in the upper layer	limiting criterion (depends on the target ecosystem; raised bog vegetation can be restored only on raised bog peat, fen – on fen type peat)
Residual peat layer thickness	≥0.5 m for restoration of raised bog vegetation; ≥0.3 m for restoration of fen vegetation
pH of upper layer peat	depends on the characteristics of residual peat layer and the target ecosystem: pH 3.4–5 is suitable for restoring raised bog vegetation; pH 5–8 – for fen vegetation
Peat decomposition degree	not important
Average groundwater table below the peat surface	up to the peat surface; site may be temporarily flooded
Average number of days in a year when the area is flooded	up to 90 days per year
Amount of stumps in peat layer	not important

Planning of works

Several aspects shall be taken into account while planning rewetting.

- ✔ The planned after-use scenario must be consistent with spatial planning documents of local municipality.
- ✔ In case if peat extraction is ongoing in the licence area, compliance of reclamation measures with documents of use of subterranean depths must be evaluated.
- ✔ Several conditions are important for successful development of peat-forming vegetation, therefore they must be evaluated: (1) micro-relief (largely depends on peat extraction method); (2) hydrological and hydrogeological conditions (water supply sources – predominantly precipitation or groundwater, flooding frequency (if any)); (3) the condition of drainage system (functionality and possibilities to block the ditches to raise the water table); (4) presence of vegetation characteristic for heavily drained peatlands: is removal of existing vegetation necessary?

Practical works

Detailed study of the area is necessary. Conditions of peat formation, peat stratigraphy, water table and the characteristics of its fluctuations, type of residual upper peat layer (fen, transitional mire, raised bog) are the main factors influencing the character of vegetation in the future. Important factors are also the depth of the peat layer, peat properties, soil water pH, mineral sediments on the bottom, peat extraction method, time since cessation of peat extraction, type of drainage during peat extraction. The expected result of spontaneous revegetation largely depends on peat decomposition degree and mineral contents of peat.

It is necessary to define the target vegetation (bog, transition mire or fen vegetation) and bear in mind that it primarily depends on the abovementioned site conditions.

When a new peat extraction project is being developed or changes in the existing one are proposed including changes in reclamation design, to re-create mire conditions, preservation of at least 0.5 m (bog vegetation) or at least 0.3 m (fen vegetation) thick layer should be planned. The peat layer will improve the water retention capability.

Drainage system should be modified according to the rewetting purpose, so that it is possible to control the water table and maintain it constantly high.

Existing vegetation must be removed if an area that has been abandoned and unreclaimed for a long time should be rewetted. The highly decomposed upper peat layer should be removed, the surface should be removed to make it was even as possible and to achieve also even distribution of water. Therefore, prior to practical works, topographic survey of the area to be reclaimed is essential for proper levelling of the surface and keeping the water table close to surface.

Surface preparation

Surface condition of the managed field is an essential precondition for the successful re-creation of mire conditions. The field surface should be as even as possible. Otherwise, after the raising of water table, the depressions will be flooded, whereas the groundwater table will be too low for mire plants in higher elevations.

In peatlands where peat extraction was ceased long time ago, the existing vegetation must be removed, as it can encumber the movement of machinery, increase evapotranspiration from surface, and reduce success of peat-forming vegetation recovery after rewetting (Rochefort, Lode 2006). In such areas, the upper layer of peat is highly decomposed, therefore first its removal and levelling is necessary before raising the water table, in order to improve establishment of mire plants. The highly decomposed upper peat layer can be removed and used for construction of dams on ditches or for filling in the ditches. Remains of tree stumps and roots can be left on site as they do not encumber the proposed after-use.

Only in relatively flat areas it is possible to achieve even distribution of water without surface modification. Relatively flat areas can be created, if peat milling is the latest used peat extraction method (Priede 2017). In this case, special levelling and milling of peat field may not be necessary, and the costs for reclamation will be lower.

To restore peat-forming vegetation and mire ecosystem functions, natural fluctuations of water table are permissible within range of +/- 30 cm from the ground surface (Konvalinková et al. 2011), therefore the field inclination should not exceed 1–2%.

When deciding on rewetting as the most appropriate after-use scenario, the total continuous area of the managed site must be taken into account, as well as its configuration and location in the landscape mosaic (forests or agricultural land, natural wind barriers, etc.) influencing the microclimate and potential wind erosion, as these factors influence the success of peatland rehabilitation. The more micro-niches, wind shelters and depressions, the better the rehabilitation success, and the diversity of the micro-niches will also ensure greater species diversity. It might be more difficult to achieve successful recovery of mire ecosystem in large continuous areas. There, the evaporation is higher, they are more exposed to wind and lack shading. Shaded areas protect the peat from strong temperature fluctuations during the day at least to some extent. Dark peat surface heats up in summer, which adversely affects plant survival (Priede 2017). When planning rewetting, it is desirable to diversify the micro-relief, which may promote the development of diverse vegetation structure. The type and amount of works should be planned for individual areas, as they will be influenced by the character of mineral ground (mineral contents, permeability, relief, variations in peat depth).

A mosaic of wet peat and periodically flooded peat is recommended. In such site, trees will not establish, but the conditions will be suitable for establishment of mire plants, e.g. *Sphagnum* mosses, cattails *Eriophorum spp., beak-rushes Rhynchospora alba, sundews Drosera spp.,* cranberry *Oxycoccus palustris in acidic environment.*

The potential for mire restoration is higher if the reclamation area is adjacent to relatively untouched mire, because it may serve as a donor area of target species. If the area is highly isolated, e.g. surrounded by forests (other than bog woodlands) or by cropland, the success of the mire revegetation may be lower (Priede, Silamiķele 2015).

If the residual peat layer is composed of raised bog peat with pH value 3–5, the site is suitable for bog species, including *Sphagnum* mosses, while slightly acidic (pH > 5–6) fen peat favours development of species-poor fen vegetation (sedges *Carex* spp., rushes *Juncus* spp., common reed *Phragmites australis*) (more on spontaneous revegetation in various conditions – see Chapter 4.4). In sites with pH > 6 and mineral-rich groundwater supply, vegetation of alkaline fens may develop, mostly consisting of the small sedges and reeds. The properties of the residual peat layer are highly important when planning reintroduction of mire plants (Priede, Silamiķele 2015).

Hydrological conditions

Ensuring appropriate hydrological conditions (groundwater table close to peat surface) is the key action in re-creation of mire conditions. Prior to rewetting, groundwater table is usually highly fluctuating, making recovery of mire impossible. The planned solution for the provision of optimal groundwater table must be specified in the reclamation design, in the peat extraction plan, or in construction design that proposes modification of drainage system.

Mineral composition and permeability of the ground sediments are very important for water retention. If ditches reach mineral deposits, as it often is in cutaway peatlands, it can be difficult to predict the result of raising the water table or it may even fail. In permeable sediments (sand, gravel), the surface water flows through the ditch base. On poorly permeable mineral ground (clay, dolomite), restoration of groundwater table may be more successful.

The water table may be achieved through targeted measures, such as filling in or blocking of ditches and other hydrotechnical structures (Priede, Silamiķele 2015). Various materials can be used for construction of dams – peat, wooden boards, logs, plastic piling and other materials. Selection of them depends on the material available on the site, their durability and transportation possibilities. Locations of dams are chosen according to relief and runoff conditions. To determine the most appropriate locations and number of dams, it is recommended to perform topographic survey, to develop a digital surface model and to perform hydrological calculations (Nusbaums 2008).

The experience of mire restoration shows that peat dams are the most effective solution for blocking of ditches. They are constructed using peat which is obtained near-on-site, and compacted by excavator bucket, therefore reducing the risk of dam leaching and improving their durability. The type and design of dams are chosen depending on site conditions (Priede, Silamiķele 2015).

If field ditches (drains established for peat extraction) are not deep, they can be preserved because after raising the water table they will fill up with water, and it will be easy to assess the water level in the area after rewetting. Over time, field ditches will overgrow with peat-forming vegetation (Nusbaums, Silamiķele 2012).

If rewetting is being planned in cutaway peatlands adjacent to peatlands where peat extraction is still ongoing, it is recommended to establish 5 m wide belts of compacted peat between both sites. These type of belts have a dam function, and they will reduce water runoff from the target area and help to maintain the necessary water table in peat extraction field (Quinty, Rochefort 2003).

Under favourable conditions, establishment of peat-forming vegetation may take only a few years. However, several decades are necessary for the development of mire characteristic vegetation structure and micro-relief.

Rewetting without the reintroduction of peat-forming vegetation

When planning rewetting of cutaway peatland, prior to practical works the site conditions must be assessed. If there is a consistently high water table, and spontaneous establishment of mire vegetation (such as *Sphagnum* mosses, cottongrasses, beak-sedges, sedges on acidic raised bog peat) takes place, then it is best to leave the site for self-regeneration, and plant reintroduction is not necessary. This situation can sometimes be observed in peat extraction areas abandoned for a long time where the drainage system does not function any longer (see Chapter 4.4).

In case of low and highly fluctuating water table, adjusting of hydrological conditions is necessary (blocking of drainage ditches, construction of dams and other hydrotechnical structures for controlling the water table). The former peat extraction fields should not suffer from dessication during the dry periods, and the water level table should not be too high during excessive rains.

Reintroduction of peat-forming vegetation

Mire plant reintroduction is important if extracted peat fields cover large, homogeous areas and there are no natural mires (donor sites) nearby. All practical works (site preparation, rewetting, harvesting of donor material, sowing or planting) must be carried out within a short time. So far in Europe and elsewhere, considerable experience has been accumulated only with reintroduction of *Sphagnum* mosses. There is still little experience with restoration of fens by reintroducing of targer plant species.

The experience acquired in North America during the last 20 years shows that that reintroduction of *Sphagnum* for restoration of peatland vegetation is a complex measure that involves raising the water table, surface preparation, sowing or planting of *Sphagnum*, and mulching (Rochefort, Lode 2006). *Sphagnum* can be reintroduced both by planting of sods (Pakalnis et al. 2008) that contain also other bog plants, and spreading of *Sphagnum* fragments, as well as spreading of species-rich hay (the last method is little tested, and can be used only for restoring fen vegetation) (Priede 2017). Preferably, donor material should be taken from sites which are being prepared for peat extraction.

Sphagnum mosses have the ability to grow from small fragments, so the obtained *Sphagnum* sods can be crushed and then spread. However, establishment and survival of *Sphagnum* fragments depends on surface micro-relief and microclimate (Pakalne 2013). *Sphagnum* fragments are more exposed to drought risk, as they are unable to accumulate water, in contrary to *Sphagnum* clusters (sods).

The donor material is spread across the prepared surface. If the area is not large, it can be done by hand. In larger areas, organic manure spreaders are used. After spreading, material must be covered with straw. During the early stage of establishment, straw creates a more moderate micro-climate, maintaining moisture, creating shadow and protecting the fragments from overheating and drying out. In a few years, straw is decomposed and do not encumber further vegetation development. More about LIFE REstore experience on *Sphagnum* reintroduction – see Chapter 6.3.3.

Contribution to climate change mitigation

The potential impact on climate change should also be evaluated when considering re-creating mire conditions as an after-use scenario. The impact on GHG emissions was estimated for a 30-year period following rewetting, assuming that these measures are implemented in an area where peat extraction has been discontinued recently and vegetation has not yet developed, but the topsoil consists of raised bog peat of low fertility. After rewetting, GHG emissions will increase by 2 t CO_2 eq./ha^{-1} year compared to the initial condition. The preservation of condition during the peat extraction was used as an alternative scenario. Total GHG emissions from this after-use scenario during the calculation period correspond to 8.2 t $CO_{2\,e}$q./ha^{-1} year.

According to the IPCC guidelines, accounting of GHG emissions is not necessary from natural ecosystems, therefore, despite the actual increase in GHG emissions after rewetting, the increase in these emissions is not accounted, and it is assumed that GHG emission reduction is equal to GHG emissions in case of status quo – 6.3 t CO_2 eq./ha^{-1} year (LIFE REstore project data). Over time, mire vegetation captures carbon and "stores" it in peat.

Indications of successful rewetting

Successful mire recovery is indicated by establishment of mire plants. Reintroduced plants have survived and are vital, their cover is increasing. Groundwater table is close to the peat surface, the fluctuations are mild. At least five years after rewetting, large proportion of the peat surface is covered by peat-forming vegetation with presence of bryophytes of mires (e.g. *Sphagnum* on acidic raised bog peat).

Indications of unsuccessful rewetting

Mire plants have not established, or their reintroduction has failed. Patches of bare peat prevail; vegetation is composed of few species, such as *Eriophorum vaginatum* and *Calluna vulgaris, bryophytes of mires are absent.* Groundwater table is lower than optimal for recovery of mire vegetation, and its fluctuations are well-pronounced (in periods of drought, the water table drops lower than -0.5 m). The upper layer of peat is dry and exposed to erosion. Dry peatlands gradually overgrow with forest. Failure can be caused by inadequate water table (too low or too high), low quality of donor material or improperly chosen target species which do not suit the particular site conditions.

Advantages

Rewetting, i.e. re-creation of mire conditions, results in reduction of the negative impact of peat extraction on mire biodiversity. In long term, rewetting along with recovery of mire vegetation and peat formation reduces GHG emissions. Re-creation of mire conditions diminishes the fire risk in the former peat extraction fields and adjacent areas. Peat-forming vegetation, including rare and protected plant and animal species, can establish in the rewetted areas. Rewetted areas can serve as important bird breeding and feeding habitats, and as stopover sites during bird migration. Also the risk of establishment and spreading of invasive species (mainly bryophyte *Campylopus introflexus*) is reduced.

Disadvantages

There is no sufficient experience in Latvia on peatland rehabilitation by reintroducing mire plant species. Until now, it has been tested only in a few small areas.

Rewetting in an area to be reclaimed may be technically complicated, time consuming and require considerable financial resources in case if the construction of specific hydrotechnical structures is necessary.

Possible works and their preliminary costs

Possible necessary works and their preliminary costs are summarized in Chapter 6.2.10.

Experience in Latvia

In Latvia, there is more than ten years of documented experience on rewetting of former peat extraction areas. In several areas, the water level rise and spontaneous restoration of mire vegetation occurred also after clogging of ditches without carrying out any targeted measures (often facilitated by beaver activity) (see Chapter 4.4). However, the practical experience on mire plant reintroduction is still insufficient.

In 2006, a former peat extraction area was rewetted in Ķemeri National Park within LIFE-Nature project "Conservation of wetlands in Ķemeri National Park" (LIFE02 NAT/LV/008496). In the north-western part of Ķemeri Mire (Figure 134), the water table was successfully raised by blocking ditches with peat dams and by building other hydrotechnical structures. In most of the area, rewetting has resulted in successful recovery of bog vegetation (Ķuze, Priede 2008). Here, rehabilitation measures were applied in an area where peat extraction was ceased more than 20 years ago. No special surface preparation or removal of vegetation was carried out, but the results are good in most of the area. Likely, revegetation was facilitated by the vicinity of undisturbed raised bog, a donor area of bog plant propagules (Priede 2013).

In the autumn 2012, experimental planting of *Sphagnum* mosses was carried out in Lielsala Mire. Here, the fragments of mosses gathered in the nearby areas were spread across partly overgrown peat fields (Cupruns et al. 2012), without special surface preparation works. In summer 2014, researchers from the University of Latvia concluded that the survival of *Sphagnum* after two years was low, mainly because the surface of the peat was too dry, or the fluctuations of groundwater table were too high (Priede, Silamiķele 2015). In the nearby rewetted area with high water table, spontaneous revegetation with *Sphagnum* and other bog plants was observed already a few years after the completion of peat extraction (Figure 135).

Figure 134. Successfully restored mire vegetation in the former peat extraction fields in Ķemeri Mire, about ten years after rewetting. Photo: A. Priede.

Figure 135. In Lielsala Mire, suitable conditions for mire recovery have been created (photo taken in 2014). Photo: A. Priede.

Experience of LIFE REstore on *Sphagnum* reintroduction is described in Chapter 6.3.3.

6.2.10. Potential works for the implementation of after-use scenarios and estimated costs

Ingrīda Krīgere

Potential works to be carried out for the implementation of particular after-use scenarios and the estimated reclamation costs are given in Table 22. Types of work are determined by the initial condition of the site. Potential differences in site conditions must be taken into account in every individual site. Estimated costs are based on average prices in 2019 and recent experience.

Table 22. Potential reclamation works and estimated costs.

Type of work	Establishment of croplands	Establishment of perennial sown grasslands	Afforestation	Establishment of large cranberry plantations	Establishment of blueberry plantations	Paludicultures	Establishment of water bodies	Rewetting	Unit	Cost, EUR	Notes
Removal of excessive vegetation	■	■	■	■	■		■	■	ha	1200–2000	
Removal of stumps and tree trunks	■	■	■	■	■	■			ha	100–500	
Levelling of surface	■	■		■	■	■	■		ha	150–250	
Cultivation of the area		■	■						ha	50	depth 0.12–0.15 m
Subsoiling up to 0.4 m depth	■				■	■		■	ha	100–700	0.4 m subsoiling
Ploughing of soil surface	■	■	■	■	■				ha	50–100	
Cultivation of soil surface		■		■	■				ha	50	
Disking	■	■	■	■	■				ha	70	
Field cleaning, removal of old construction machinery, construction materials, other waste	■	■	■	■	■	■	■	■	ha	50	
Removal and levelling of old technological roads	■	■		■	■	■	■	■	ha	300	
Establishment of technological roads				■	■				ha	400–600	compacted peat roads
Dismantling of drainage structures (pumping stations and pipelines)							■		pieces	2500	
Modification of existing drainage system	■	■	■	■	■	■	■	■	ha	500–1500	
Establishment of new drainage system	■	■	■	■	■				ha	1500–2500	
Establishment of subsurface drainage system	■	■	■	■	■				ha	3700	
Establishment of ditches	■	■	■	■	■				ha	500–1500	main ditches: 1 ha – 20; 40; 540 m, drains – 500 m
Modification or deepening of existing ditches				■	■				ha	70–800	

Table 22 continued

Type of work	Establishment of croplands	Establishment of perennial sown grasslands	Afforestation	Establishment of large cranberry plantations	Establishment of blueberry plantations	Paludicultures	Establishment of water bodies	Rewetting	Unit	Cost, EUR	Notes
Establishment of pond for watering				■	■				pieces	2500-3000	
Design for modification of drainage systems and hydrotechnical structures							■	■	pieces	300	
Soil agrochemical tests, water analyses		■	■	■	■	■		■	1 unit	50	
Liming material		■	■			■			t	40–120	
Liming		■	■			■			ha	30–60	
Spreading of organic manure			■						ha	60	
Spreading of ash			■						ha	70	
Spreading of mineral fertilisers		■	■	■	■	■			ha	20–40	
Purchase of mineral fertilisers		■	■	■	■	■			ha	250–400	
Purchase of black alder seedlings			■						1000 pieces	175–240	
Purchase of pine seedlings			■						1000 pieces	200–250	
Purchase of birch seedlings			■						1000 pieces	175–240	
Purchase of poplar seedlings			■						1000 pieces	440	
Tree planting			■						ha	120	
Purchase and sowing of seeds of perennial grasses		■							ha	100–150	
Establishment of watering system				■	■				ha	5000–6000	
Drip irrigation system				■	■				pieces	4700	
Drippers and other materials				■	■				ha	2150	
Pipelines, construction costs				■	■				ha	4270	
Frost protection irrigation system				■	■				pieces	5700	
Pump unit				■	■				ha	570	
Weeding				■	■				h	5–6	
Establishment of watering system for large cranberries				■					ha	1900	
Establishment of furrows for large cranberries					■				ha	620	
Purchase and planting of highbush blueberries (costs depend on planting distance and age of seedlings)					■				ha	10000–14000	

Table 22 continued

Type of work	Establishment of croplands	Establishment of perennial sown grasslands	Afforestation	Establishment of large cranberry plantations	Establishment of blueberry plantations	Paludicultures	Establishment of water bodies	Rewetting	Unit	Cost, EUR	Notes
Purchase of lowbush blueberry seedlings (costs depend on planting distance)									ha	45000–55000	
Purchase of large cranberry planting material									t	60000	
Working of large cranberry vines into the soil by discs or mill									ha	450	
Sawdust									m^3	500	
Spreading of sawdust									ha	150–200	
Construction of wooden dams									pieces	400	
Construction of peat dams									pieces	500–1200	
Construction of corrugated dam									pieces	300-600	
Gathering of Sphagnum donor material									kg	1.6	
Reintroduction of mire plants (planting, spreading)									ha	1000	
Transportation of planting material (mire plants) to planting site									km	5	

6.2.11. Comparison of ecosystem services in various after-use scenarios

Aija Peršēvica, Agnese Priede

Most land use types can provide various types of ecosystem services. If land use is primarily related to economic activity, it is obvious that the most important ecosystem services in this area are provisioning services. However, the high value of natural and slightly disturbed sites is based on their ability to provide regulation services.

When evaluating the use of land after reclamation from ecosystem services point of view, it is important to realize that areas which provide provisioning services of high values are artificially maintained systems that require regular investment and provide low regulation and cultural services. These are intensive production areas (cropland, perennial sown grasslands).

Establishment of semi-natural, partly functional ecosystems is promoted by some of the after-use scenarios described in Chapter 6.2.2–6.2.9. Such ecosystems provide both provisioning and regulation services, but they are artificially maintained and regular management is required (berry plantations, paludicultures, afforested areas).

Rehabilitation of peatland ecosystem and, to a large extent, establishment of water bodies are after-use scenarios which allow recovery of natural or semi-natural ecosystems which are self-regulating and self-sustaining. For these ecosystems, regular maintenance is not necessary in the future. Their provisioning services are not as high as in artificial and semi-natural systems, but they provide important regulation and cultural services in the long term.

In Table 23, ecosystem services of after-use scenarios analysed in Chapter 6.2 are summarized.

Table 23. Land use types after implementation of after-use scenarios, and related ecosystem services.

Land use type after implementation of after-use scenario	Ecosystem services provided
Cropland	The main ecosystem services provided by cropland and crops cultivated there are provisioning services (food, fodder, raw materials for bioenergy production and pharmaceuticals, and other material resources). However, these areas and their provisioning services depend on regular maintenance (drainage, soil amelioration, etc.) and on ecosystem services that can only be provided by natural ecosystems, for example, pollination and biological pest control. The self-regulation ability of these artificial systems and thus the regulation services is of very low value. Biodiversity is very low, and the landscape's aesthetic value is low (intensively used agricultural production areas), and therefore cultural services are also of very low value.
Perennial sown grasslands	Perennial sown grasslands provide provisioning services such as fodder and resources for bioenergy production. The range of regulation services provided by sown grasslands on drained peat soils is much lower than in semi-natural grasslands and natural ecosystems (e.g. fens). Perennial sown grasslands, similarly as cropland, are artificially maintained systems, and their existence and offered provisioning services depend on functioning of drainage system and agrotechnical measures. The biodiversity in such areas is very low. Similarly to cropland, they are artificially maintained areas of intensive agricultural production, with a very low value of cultural services.
Berry plantations	Cultivation of berries (large cranberries, highbush and lowbush blueberries) is an agricultural activity that provides provisioning services of high values (berry yields). The value of regulatory services is relatively low, as these are artificially maintained systems. However, such plantations are important for erosion protection, carbon capture, water flow regulation, etc. Biodiversity is low. As these are agricultural production areas, the cultural services are also very low.
Afforested areas	Forests are diverse ecosystems that provide habitats for a large number of species. However, biodiversity of artificially created woodlands on drained peat soils is lower than in natural forests. The greatest contribution of ecosystem services of forests, including forests established in reclaimed areas, is their ability to provide high-quality regulation services: they capture carbon, regulate climate and microclimate, cycles of water and nutrients, provide clean air, reduce soil erosion. Forests provide important provisioning services (wood and non-wood resources, energy resources, etc.). Forests also provide valuable, diverse cultural services (such as wildlife watching, physical and passive recreation, aesthetic enjoyment, environmental cognition, research, etc.), although the value of these services in artificially afforested peatlands is lower than in natural and near-natural forests.
Water bodies	Aquatic ecosystems provide important ecosystem services that can not be provided by ecosystems of other types, for example, fish for food, and various material resources (reeds as construction material and biomass for various applications). Artificial water bodies, though they are human-created ecosystems, are involved in regulation of water and nutrient cycles, water purification, climate and microclimate regulation. At the same time, aquatic ecosystems provide diverse and valuable cultural services (recreation, wildlife watching, environmental cognition, research, etc.).
Paludiculture	The most important ecosystem services of paludicultures are provisioning and regulation services. Biomass from various paludiculture crops can be used for food, fodder, fuel production, as a raw material for bioenergy production and construction, and pharmaceuticals. Although the purpose of paludiculture plant cultivation is productive use of wetlands and not conservation of biodiversity, this use of peat soils can restore and maintain such ecosystem services as carbon sequestration and storage, storage and regulation of water and nutrients. The value of the provided cultural services is not high. However, certain paludiculture types can be significant in maintaining the nature diversity, thus providing minor opportunities for environmental cognition and recreation.
Rewetted areas	The most important value of mires is their ability to provide diverse and highly valued regulation services such as biodiversity conservation, water and nutrient cycles, water purification, erosion control, and more. Carbon capture is one of the most important regulation services provided by intact mires. This way, rewetting makes a significant contribution to climate change mitigation. Such areas provide remarkable provisioning services (wild berries, medicinal plants, products of beekeeping), and important recreational possibilities (wildlife watching, recreation, nature cognition, research). Rewetted former peat extraction areas provide a full range of ecosystem services characteristic to natural mires only after a longer period. However, after successful rehabilitation, they become self-regulating ecosystems that do not require artificial maintenance.

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6.3. Experience of LIFE REstore in implementation of after-use scenarios and rewetting of drained peatland

6.3.1. Afforestation demo site

Dagnija Lazdiņa, Santa Neimane, Santa Celma

Summary

After the cessation of peat extraction, it is not always possible to restore mire ecosystem, for example, if hydrological conditions, peat structure and properties are irreversibly changed, or large investments are needed. Mire restoration is not possible in areas neighbouring with active peat extraction fields, as the drainage system is operating, thus its impact on the area usually cannot be efficiently prevented. One of the solutions that have been widely used, for example, in Finland, Sweden and the British Isles, is afforestation. It ensures both economic benefits and carbon sequestration in tree biomass.

During the LIFE REstore project, in 2017 a demo site was established in the central part of Kaigu Mire. In a sector where peat extraction was completed leaving at least 50 cm deep residual peat layer (raised bog peat, pH 5–5.5), tree species which are fast-growing at juvenile stage were planted: poplar *Populus* spp. v. *Vesten*, silver birch

Betula pendula, black alder *Alnus glutinosa*, as well as Scots pine *Pinus sylvestris*. These are species with a broad ecological tolerance, able to grow in various conditions. Here, the drainage system was restored. i.e. drains were cleaned and the water table was adjusted. Soil was improved using wood ash. To evaluate vegetation recovery and growth of the planted trees in relation to peat layer neutralization and influence of added macro-elements (phosphorus-potassium) and micro-elements in the ash, several experimental plots were established where 0, 5, 10 un 15 t ha^{-1} of wood ash were spread across the topsoil.

In the first year after soil improvement, 27–39 plant taxa were recorded in ground vegetation. In the second year, their number increased to 33–42, depending on the type of soil improvement. In the first vegetation season, more diverse vegetation was found in sampling sites where the highest amount of wood ash was applied. In the second year, the highest number of plant taxa was found in plots where 10 t ha^{-1} of wood ash were applied. In areas where soil was improved using wood ash, the highest growth increment was observed for poplars, birches and alders. In the former production fields where wood ash was not applied, lack of nutrients was observed in birch and poplar plantations where survival rate was by 10% lower. For other tree species, mostly visual differences were observed, such as smaller or paler leaves or needles.

Introduction

After the cessation of peat extraction, it is not always possible to restore mire ecosystem, for example, if hydrological conditions, peat structure and properties are irreversibly changed (Höper et al. 2008), or large investments are needed. Usually mire restoration is not successful in sites where peat extraction is being continued, as the drainage system is still operating, and its impact on the entire peatland mostly cannot be sufficiently prevented. In countries where peat extraction is an important economic sector (such as Finland, Sweden, and the British Isles), afforestation as an after-use type is considered to be one of the easiest, economically viable and environmentally friendly solutions, especially if the area has previously been covered by forest or in case if the layer with ancient tree remains has been exposed during the peat extraction (Woziwoda, Kopeć 2014). Wood ash can be used for soil amelioration, liming and nutrient input (Mandre et al. 2010; Kikamägi et al. 2013; Ots et al. 2017). Vegetation which develops after the soil amelioration plays a very important role in nutrient cycling and carbon sequestration in extracted peatlands (Huotari et al. 2009, 2011). Scots pine *Pinus sylvestris*, silver birch *Betula pendula* and black alder *Alnus glutinosa* are able to grow on organic soils with fluctuating water table which are characteristic in extracted peatlands (Sottocornola et al. 2007; Huotari et al. 2008; Hytönen, Saarsalmi 2009; González et al. 2013; Bebre, Lazdiņa 2017; Lazdina et al. 2017). Researchers in Belgium have created poplar clones suitable for afforestation of peat soils, and one of the results of this work is female poplar clone *Vesten*.

In order to test the afforestation as an after-use scenario for extracted peatlands and to find out the most effective, optimal dose of biological fertilizer – wood ash – for various tree species, an area of 9 ha was afforested in Veļu Mire, a part of Kaigu Mire, within the LIFE REstore project.

Material and methods

Before the afforestation experiment, the demo site was partially overgrown with trees and reeds. The residual peat consisted of consecutive layers of fen, transitional mire and raised bog peat. The mineral ground under the peat is uneven, so the thickness of the peat layer varied even at small distances. In the afforestation site, it was thicker than 0.5 m, reaching a depth of more than one metre. The upper layer of the residual peat consisted of acidic moderately decomposed raised bog peat.

In the spring 2017, drains were cleaned in an area of 9 ha (56°43'42.1"N, 23°34'33.3"E). First of all, the excessive vegetation (reed, trees) was removed (Figure 136). Then, peat that was excavated during ditch cleaning was milled and dispersed across the former production fields.

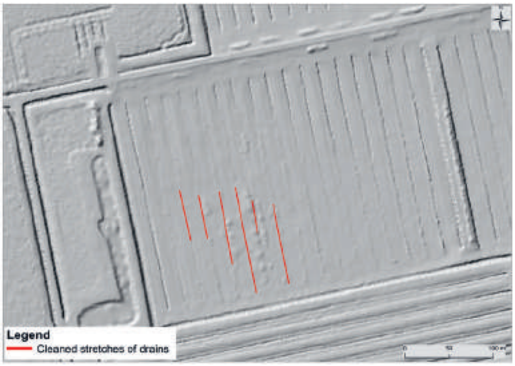


Figure 136. LiDAR-based digital surface model of the afforestation demo site. Map prepared by A. Rudusāne using the digital surface model, © Latvian Geospatial Information Agency.

After the cleaning of drains, wood ash – material containing phosphorus, potassium and trace elements – was dispersed and incorporated into the soil. Wood ash was obtained from SIA "Fortum", the nearest major energy producer. The wood ash was transported to the demo site, packed in bulky bags. Knowing the weight of one bag made the dosing easier. For the spreading of wood ash, a tractor equipped with extra wheels was used, to ensure that the pressure on ground surface is reduced. The prototype of the ash dispersing device was produced by the Latvian State Forest Research Institute "Silava" (hereinafter – LFRI Silava) (patent No LV 15075 B). Wood ash was moistened before application, in order to reduce dustiness (Figure 137). Dosing was carried out by changing the speed of the tractor movement or by repeated movement along the same drains. In order to evaluate the agrochemical changes of soil agrochemical parameters induced by fertilizing with wood ash, soil samples were collected from the former peat production fields of the first block (Figure 138) – three topsoil samples in the middle of the former production field. Soil samples were collected in the second year after the ash application – at the beginning of the vegetation season. Agrochemical parameters were determined in accordance to methods described by Bardule et al. (2003).

Figure 137. The process of wood ash dispersal. Photo: G. Spalva.: A – Transportation and loading of wood ash; B – kMoisturising of wood ash; C – Dispersal of wood ash; D – Dispersed ash before its incorporation in the soil

For the liming and fertilization, wood ash doses were chosen as recommended in Finland and Sweden – 5–10 t ha^{-1}, as well as 15 t ha^{-1} – doses which would allow long-term observation of the relation of the application of various soil amelioration materials and vegetation development and tree growth (Figure 138). Wood ash was dispersed and incorporated into the soil.

After the site preparation, trees were planted in May 2017. The distance between the tree rows was 3.5 m, among the trees – 2.5 m; 2.5 m wide belt was left along the drains. Each variant was arranged in three replications. Each species was planted in the former production fields on both sides of the drain; 40 x 45 m plots were established, with a separation zone of three metres. Container seedlings of pine, birch and alder, as well as cuttings of poplar (1.8 m) were planted.

The preparation of drains and former production fields for tree planting was based on the reclamation design prepared by SIA "EnviroEnGen" for the forest planting in Kaigu Mire (EnviroEnGen 2017). The condition of the particular residual peat was taken into account in this plan. The characteristics of the peat field prepared for afforestation were appropriate to ensure that the established forest would correspond to one of the forest site types on drained peat soils. Also, the results of the studies on peatland afforestation in Latvia and other countries were used (Bebre, Lazdiņa 2017). The amount of wood ash (liming material), its moisturising and spreading, as well as its application in particular sites were calculated in accordance to recommendations by EnviroEnGen (2017). The ash dispersal work was supervised by Modris Okmanis, a research assistant at LFRI Silava.

Planting was supervised by Ieva Bebre, a research assistant at LFRI Silava. The planned technical work was carried out by SIA "Laflora". For planting of pines, birches and alders, container seedlings were used as they can be easily planted both using a shovel or planting tube. Compared to other available types of planting material, container seedlings are less exposed to risk of drying out, because of their compact root system which is developed in enriched peat (LVM, Sēklas un stādi). The poplars were planted with 1.8 m long cuttings that were inserted into the soil at a depth of at least 50 cm (Zeps et al. 2011).

Road															
		1. BLOCK				2. BLOCK				3. BLOCK					
	Row	1	2	3	4	5	6	7	8	9	10	11	12	13	14
236 m	45 m	Ma	Ma	Pa	Pa	D	D	P	P	B	B	Ma	sP / sB	sE / sMa	Ma
	3 m														
	45 m	B	B	Ma	Ma	Pa	Pa	D	D	P	P	B	sE / sMa	sB / sP	B
	3 m														
	45 m	P	P	B	B	Ma	Ma	Pa	Pa	D	D	P	D	D	P
	3 m														
	45 m	D	D	P	P	B	B	Ma	Ma	Pa	Pa	D	sP / sB	sE / sMa	D
	3 m														
	45 m	Pa	Pa	D	D	P	P	B	B	Ma	Ma	Pa	sE / sMa	sP / sB	Pa
		20 m	20 m	20 m	20 m	20 m	20 m	20 m	20 m	20 m	20 m	20 m	20 m	20 m	20 m
Dose of fertlliser, t/ha		**0**	**5**	**10**	**15**	**0**	**5**	**10**	**15**	**0**	**5**	**10**	**15**	**10**	**15**
													5	**0**	

Figure 138. Planting scheme (Pa – poplar *Populus spp.* v. *Vesten*, B – silver birch *Betula pendula*, Ma – black alder *Alnus glutinosa*, P – Scots pine *Pinus sylvestris*, D – spontaneous afforestation). "s" in columns 12 and 13 indicates territories where tree seeds were sown (additionally also E – Norway spruce *Picea abies*). Double-line depicts drains.

To test afforestation possibilities by sowing tree seeds, an experiment was carried out in spring 2018 (Figure 139, row 12 and 13). Sowing beds were spatially arranged in the same way as the plots where seedlings were planted. Seeds were obtained from seed source plantations by JSC "Latvijas valsts meži". In each sowing bed, either five seeds of birch, or three seeds of alder, or three conifer seeds (Scots pine or Norway spruce) were sown. Due to summer drought, only pine seeds germinated after the first vegetation season, therefore sowing results were evaluated after the second season.

Tree height and survival were evaluated in the centre of each replication. Trees were measured in all rows, from the 6th to the 14th tree. Vegetation was recorded in six sampling plots of size 2.5 m by 3.5 m, between the 9th and 11th trees, in the 2nd to 5th and 1st to 4th rows of adjacent peat fields (Figure 139). Vegetation was recorded at the end of the summer of 2017 and 2018. Tree height was measured in winter after the vegetation season.

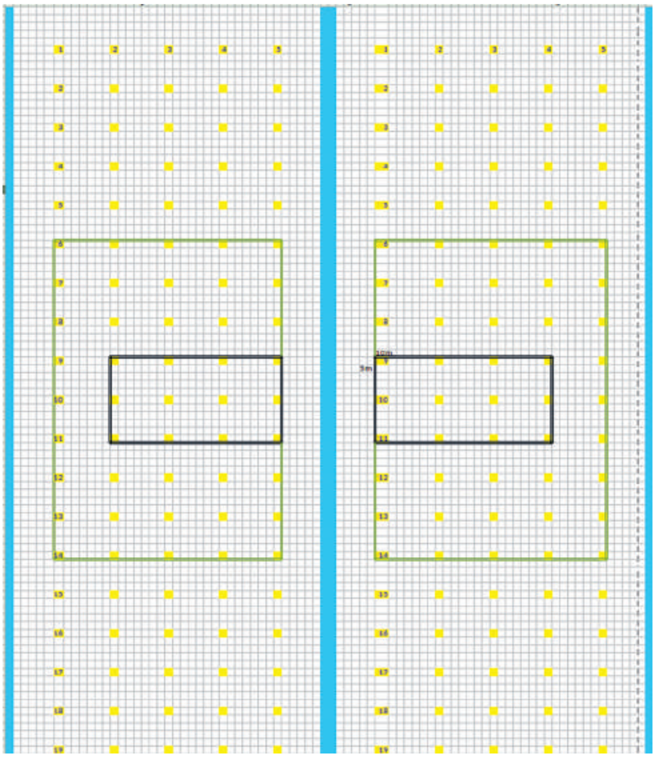


Figure 139. Arrangement of tree (green) and vegetation (black) sampling plots (yellow circles – location of planted trees, blue lines – drains).

Using this vegetation sampling design, vegetation around the same planted tree species was described on both sides of the drain. Planted trees were excluded when recording the vegetation composition.

Reed was mown at least once a year. During the first years, other naturally occurring wild plant species were not significant competitors to the planted trees, thus the ground vegetation was not removed. Soil scarification between the rows was also not carried out in order to gather the information on the natural vegetation development, including spontaneous establishment of trees. Before the winter, repellents were applied on planted trees. In 2019, agrotechnical maintenance works are planned, except for "spontaneous afforestation" plot where both the planted trees and selected other trees were left untouched. For wooded and herbaceous species, it is planned to determine biomass amount and recalculate biomass per unit area depending on the amount of wood ash used for fertilization.

By the end of 2018, greenhouse gas measurements were done in sampling sites which were located below the crowns of poplars and in site where reed introduction occurs (Figure 149) (see Chapter 3).

Figure 140. Greenhouse gas measurement site in tree plantation. Photo: S. Neimane.

Results and discussion

In the first years after tree planting, the most important indicators of successful afforestation were development of vegetation cover and establishment of tree seedlings. The survival of trees, except for black alder, can be considered as excellent, as up to 96% of planted trees survived. After planting, black alder leaves were damaged by the alder leaf beetle *Agelastica alni*, and this could be a reason for a comparatively low survival of alders. However, also their survival can be assessed as very good, regardless of damage caused by alder leaf beetle (Table 24).

Table 24. Survival of tree seedlings in the first and second growing season.

Species	**Hybrid poplar clone (Populus Vesten)**		**Silver birch (Betula pendula)**		**Black alder (Alnus glutinosa)**		**Scots pine (Pinus sylvestris)**	
Growing season	1.	2.	1.	2.	1.	2.	1.	2.
Ash, t ha^{-1}								
0	100%	93%	96%	85%	95%	89%	100%	99%
5	100%	99%	99%	97%	97%	82%	99%	98%
10	100%	99%	98%	96%	91%	80%	100%	99%
15	100%	99%	98%	96%	89%	86%	100%	100%

Spontaneously developed vegetation

Vegetation cover developed already in the first year after planting. In unlimed (control) areas only few plants were observed. In limed areas, vegetation cover was denser (Figure 141).

Figure 141. In the front – unimproved soil. On the other side of the drain – area which was fertilised using wood ash, 5 t ha-1. The photo was taken in the end of the second vegetation season. Photo: S. Neimane.

Alongside the edges of the former production fields, vegetation was dominated by reeds *Phragmites australis*. In the entire demo site, spontaneous establishment of downy birch *Betula pubescens*, silver birch *B. pendula*, Scots pine *Pinus sylvestris*, common aspen *Populus tremula*, and various willow species (*Salix* spp.) was observed. Ground vegetation was dominated by pioneer species, mostly herbaceous plants, in some places also the bryophyte *Polytrichum* spp. (Annex 4). In the first year, after soil amelioration, 27–39 plant taxa were recorded. In the second year, their number increased to 33–42. In the first season, more diverse vegetation was observed in plots where 15 t of wood ash per hectare was applied; in the second year – in plots where 10 t of wood ash per hectare were applied.

In 2017, excess moisture was drained by ditches; therefore tree development was not adversely affected by the atypically high precipitation of that summer. In the hot, dry summer of 2018, however, the top layer of the soil dried out and heated up, and at the end of the season there was no water in the drains any longer (Figure 142). Due to extremely dry conditions, morphological changes of several herbaceous species were observed making species identification difficult, therefore some taxa were identified only at the genus level.

Figure 142. Ditch with poplar cuttings in the background (May 24, 2018). Photo: S. Neimane.

The black alder, a species occurring in wetlands, proved to be more sensitive to unstable weather conditions than other tree species, therefore its survival was lower.

Average height of trees and the agrochemical parameters of the soil

At the end of the first season, when height of trees was estimated, better growth of poplars and alders was observed in plots where soil was improved using 10 t ha^{-1} of wood ash (Figure 143).

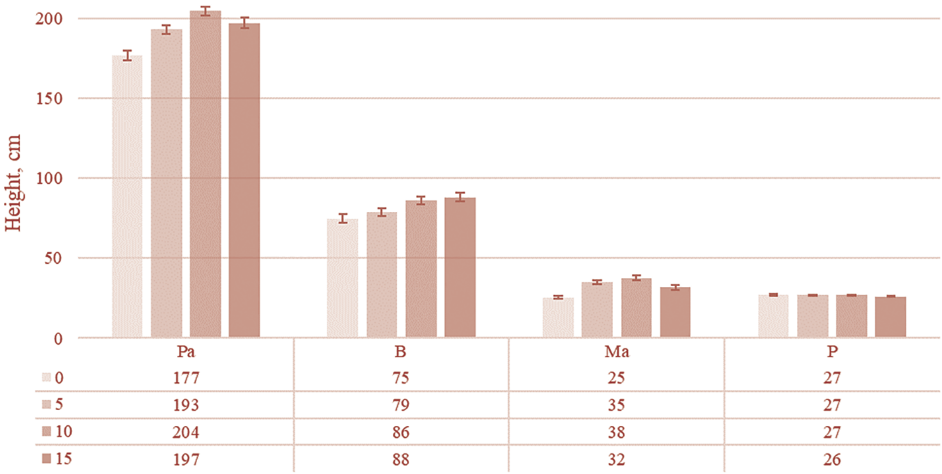


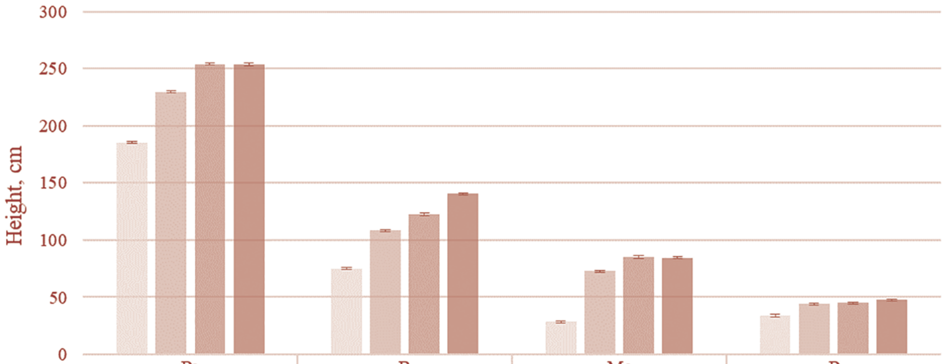
Figure 143. Average height (with standard error) of tree seedlings (Pa – poplar, B – silver birch, Ma – black alder, P – Scots pine) after the first growing season in plots with various doses of wood ash fertilisers (0 t ha^{-1}, 5 t ha^{-1}, 10 t ha^{-1}, and 15 t ha^{-1}).

The results of soil agrochemical analyses illustrate the processes in the soil after ash application – the pH and the concentration of Ca, Mg, K, P in the soil correlate with wood ash doses. Organic matter in peat is being decomposed, nitrogen and other mineral elements are released and become available to plants (Table 25).

Table 25. Soil agrochemical parameters.

Wood ash incorporated in the soil	pH_{CaCl2}	Total C., g kg^{-1}	Total N., g kg^{-1}	P, g kg^{-1}	HNO_3 extractable		
					K, g kg^{-1}	Mg, g kg^{-1}	Ca, $g^{-1}g$
Control	3.5	554.6	16.2	0.2	0.1	1.0	11.1
5 tha^{-1}	4.2	530.4	13.4	0.3	0.3	1.5	13.5
10 tha^{-1}	4.8	529.8	13.7	0.5	0.7	2.1	18.7
15 tha^{-1}	5.9	483.0	12.1	0.8	1.7	2.8	24.9

At the end of the second vegetation season, the difference between control and fertilized plots became more distinct, compared to the first year. This may be explained by peat decomposition processes or the use of nutrient reserves in the seedling containers. For all the planted tree species, tree growth in unfertilised plots was lower than in fertilised ones, and withering of treetops was observed. After the first growing season, the highest growth of poplars was observed in plots where 10 t ha^{-1} of wood ash was applied. Interestingly that after the second growth season, there was no longer any difference in height between the poplars fertilized with 10 t ha^{-1} and 15 t ha^{-1} of wood ash (Figure 144).



	Pa	B	Ma	P
0	185	75	28	34
5	230	108	73	44
10	254	123	85	45
15	254	141	84	47

Figure 144. Average height and standard deviation of trees (Pa – poplar, B – silver birch, Ma – black alder, P – Scots pine) after the second growing season, in plots with different doses of ash fertilizer (0 t ha^{-1}, 5 t ha^{-1}, 10 t ha^{-1}, and 15 t ha^{-1}).

In the limed sample plots, leaves and needles of trees were greener than in the unlimed ones. In control plots, the appearance of the planted trees indicated nutrient deficiency (Figure 145).

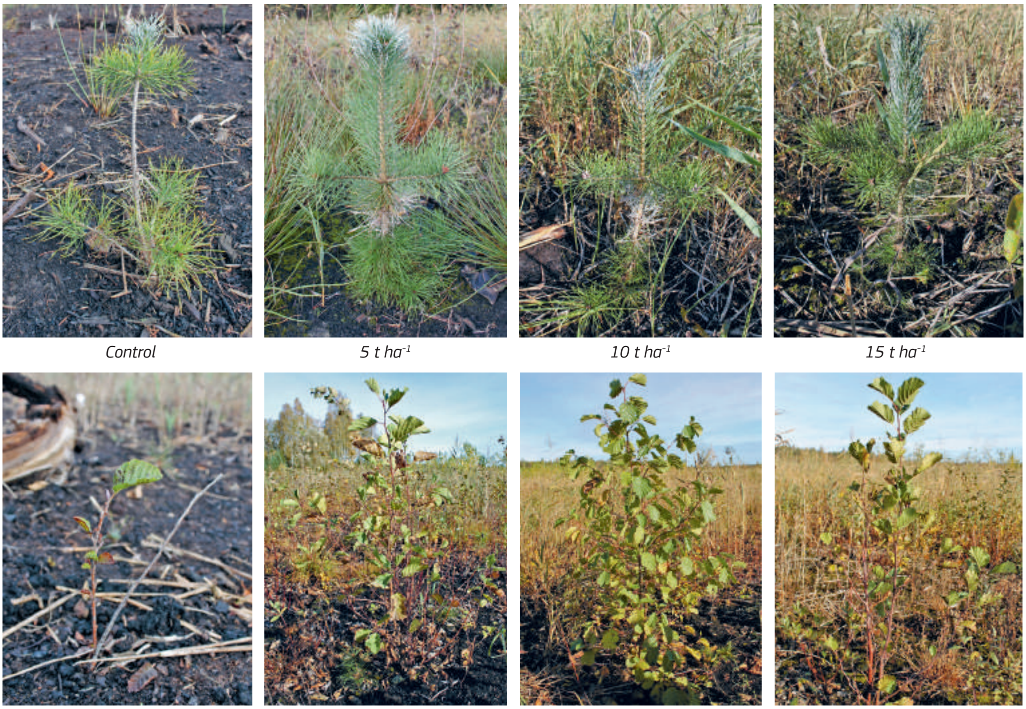


Figure 145. Seedlings of pines and alders in plots with various wood ash doses (second season, August). Photo: S. Neimane.

In the control plots, withered treetops were observed for birches, but they successfully regenerated from lateral shoots. In the improved soils, top withering of seedlings was less frequently observed, and plants were visually more vital and had larger increments. During the first two seasons, browsing by cervids was prevented by application of repellents and by leaving natural vegetation, willows and aspen on site.

After the end of the LIFE REstore project, the area will serve as a long-term demonstration site where scientists, in cooperation with practitioners, will be able to conduct research and promote afforestation as one of the reclamation techniques.

Conclusions

- ✔ Agrochemical properties in the demo site were improved by the application of wood ash: (1) soil acidity was reduced from pH_{CaCl2} 3.5 by 0.7–0.8 units per every 5 t of dispersed material (with 5 t ha^{-1} of wood ash, pH_{CaCl2} increased to 4.2; with 10 t ha^{-1} – up to 4.8; with 15 t ha^{-1} – up to 5.9); (2) the soil was enriched with calcium, magnesium, phosphorus and potassium; (3) release (decomposition) of mineral nutrients bound in organic matter was facilitated.
- ✔ Vegetation development was supported by incorporation of wood ash in the topsoil: (1) ground vegetation had established – 33–39 herbaceous plant taxa; (2) spontaneous establishment of trees was observed – the most common tree species were *Betula pubescens*, *B. pendula*, *Populus tremula*, various *Salix* spp. species, including *S. caprea*.
- ✔ In plots without soil amelioration, the planted trees were less vigorous during the second vegetation season. Visually observable signs indicated lack of macro-nutrients, thus additional nutrient inputs, i.e. fertilization is necessary here, in order to maintain the planting.
- ✔ In plots where no additional nutrients were applied, the vegetation was sparse – plants were solitary or in groups.
- ✔ Trees in the fertilised plots were vital. At the end of the second growing season, their height was significantly higher than that in the unfertilised control plots.
- ✔ Considering that the residual peat layer was thicker than 30 cm and the water table was adjusted, according to the forest site type classification in Latvia, the plantation corresponds to *kūdrenis* (forests on drained peat soils). Depending on the composition of planted and naturally established tree species, it is expected that in future these woodlands will correspond to forest site types *Myrtillosa turf. mel.* or *Oxalidosa turf. mel.* with relevant vegetation.
- ✔ The areas affected by peat extraction can be afforested without interrupting the peat extraction in adjacent areas.
- ✔ Afforestation would provide economic benefits in the future, promote soil shading and carbon sequestration in tree biomass in long term.
- ✔ If drains and collection ditches in the plantation areas will not be maintained in the future, the development of conditions characteristic to forests on wet peat soils is expected, and the corresponding forest site types will develop.

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Annex 4. Plant taxa in sample plots with different doses of wood ash, in the first and second growing season

		Ash dose (t ha^{-1})							
		0		5		10		15	
Growing season		1.	2.	1.	2.	1.	2.	1.	2.
Total number of species		27	33	37	39	38	42	39	36
Scientific name of species/ genus	**English name of species/ genus**								
Betula pendula	Silver birch	X	X	X	X	X	X	X	X
Betula pubescens	Downy birch	X	X	X	X	X	X	X	X
Brassica spp.	Cabbages	X	X	X	X	X	X	X	X
Calamagrostis spp.	Red grass	X	X	X	X	X	X	X	X
Carex spp.	Sedges	X	X	X	X	X	X	X	X
Cirsium arvense	Canada thistle	X	X	X	X	X	X	X	X
Epilobium spp.	Willowherbs	X	X	X	X	X	X	X	X
Juncus articulatus	Jointleaf rush	X	X	X	X	X	X	X	X
Juncus effusus	Common rush	X	X	X	X	X	X	X	X

		Ash dose (t ha^{-1})							
		0		5		10		15	
Phragmites australis	Common reed	X	X	X	X	X	X	X	X
Picris hieracioides	Hawkweed oxtongue	X	X	X	X	X	X	X	X
Pinus sylvestris	Scots pine	X	X	X	X	X	X	X	X
Polygonum persicaria	Lady's thumb	X	X	X	X	X	X	X	X
Populus tremula	Common aspen	X	X	X	X	X	X	X	X
Salix spp.	Willows	X	X	X	X	X	X	X	X
Taraxacum officinale	Common dandelion	X	X	X	X	X	X	X	X
Tussilago farfara	Coltsfoots	X	X	X	X	X	X	X	X
Salix caprea	Goat willow	X	X	X	X	X	X		X
Chamaenerion angustifolium	Great willowherb	X		X	X	X	X	X	X
Eupatorium cannabinum	Hemp-agrimony		X	X	X	X	X	X	X
Rubus idaeus	Red raspberry	X	X	X	X	X	X		
Agrostis tenuis	Common bent	X		X	X	X	X	X	
Hieracium spp.	Hawkweeds		X		X	X	X	X	X
Lycopus europaeus	Gypsywort	X	X		X		X	X	
Eriophorum vaginatum	Hare's-tail cottongrass	X		X	X			X	X
Arabidopsis thaliana	Thale cress	X		X		X	X	X	
Juncus tenuis	Slender rush	X		X		X	X	X	
Polytrichum spp.	Haircap moss	X		X		X		X	X
Bidens tripartita	Trifid bur-marigold		X	X	X	X	X		
Conyza canadensis	Canadian horseweed		X		X	X	X		X
Stellaria spp.	Starworts		X		X		X	X	X
Lamium spp.	Dead-nettles			X	X	X	X		X
Echinochloa crusgalli	Jungle rice			X	X		X	X	X
Rumex acetosella	Red sorrel			X	X		X	X	X
Senecio vulgaris	Common groundsel		X		X		X		X
Sonchus arvensis	Milk thistle		X		X		X		X
Crepis spp.	Hawksbeards		X	X				X	
Typha angustifolia	Lesser bulrush		X			X	X		
Scirpus sylvaticus	Wood club-rush			X		X		X	
Plantago major	Broadleaf plantain			X				X	X
Arctium spp.	Burdocks					X	X	X	
Equisetum sylvaticum	Wood horsetail		X		X				
Plantago lanceolata	Ribwort plantain		X						X
Tripleurospermum perforatum	Scentless false mayweed			X	X				
Picea abies	Norway spruce				X		X		
Rumex acetosa	Red sorrel				X		X		
Linaria vulgaris	Common toadflax					X	X		
Chenopodium spp.	Goosefoots					X		X	
Mycelis muralis	Wall lettuce					X		X	

		Ash dose (t ha^{-1})							
		0		5		10		15	
Solidago canadensis	Canada goldenrod						X		X
Calluna vulgaris	Common heather							X	X
Urtica dioica	Common nettle							X	X
Cirsium palustre	Marsh thistle	X							
Frangula alnus	Alder buckthorn		X						
Gnaphalium uliginosum	Marsh cudweed		X						
Silene vulgaris	Bladder campion			X					
Sonchus asper	Prickly sow-thistle			X					
Trifolium repens	White clover			X					
Arctium tomentosum	Woolly burdock				X				
Sagina procumbens	Procumbent pearlwort				X				
Cerastium holosteoides	Mouse-ear chickweed					X			
Cirsium oleraceum	Cabbage thistle					X			
Viola arvensis	Field pansy					X			
Fragaria vesca	Wild strawberry						X		
Valeriana officinalis	Valerian						X		
Polygonum spp.	Knotweeds							X	
Solidago spp.	Goldenrods							X	
Luzula pilosa	Hairy wood-rush								X

6.3.2. Highbush blueberry and large cranberry plantation demo site

Juris Pētersons, Andis Lazdiņš, Aija Peršēvica, Aldis Kasakovskis

Summary

The cultivation of highbush blueberry *Vaccinium corymbosum* and large cranberry *Vaccinium macrocarpon* is one of the after-use scenarios in areas affected by peat extraction. In order to verify in practice the suitability and possibilities of this after-use scenario for extracted peatlands in Latvia, the cultivation of both species has been tested during the LIFE REstore project. Both the advantages and disadvantages of this after-use scenario were evaluated.

After preparing the site, planting material was purchased and planted. Highbush blueberries were planted in Kaigu Mire (in an area of 4.2 ha) and large cranberries in Kaudzīšu Mire (3.4 ha). During the lifetime of LIFE REstore project and after the end of the project, landowners continue to maintain the plantations.

This subchapter provides insight into greenhouse gas emissions from thus type of plantations, as well as ecosystem services provided by this after-use scenario.

Introduction

The cultivation of highbush blueberries *Vaccinium corymbosum* (Figure 146) and large cranberries *Vaccinium macrocarpon* (Figure 147) are among the most promising after-use scenarios in areas affected by peat extraction. It is also the most economically advantageous solution if compared to other after-use scenarios used in Latvia (see Chapter 6.4).

Figure 146. Highbush blueberries. Photo: J. Nusbaums.

Figure 147. Large cranberries. Photo: M. Pakalne.

Both highbush blueberries and large cranberries grow well in peat, as the moisture, acidity and other conditions are suitable. The cultivation of these berries is economically justified, as the climate conditions in Latvia are favourable (Apše, Kārkliņš 2013). In Europe the production of these berries is low, largely due to unsuitable climatic conditions. However, the market demand is high.

In order to verify in practice the suitability and possibilities of this after-use scenario in Latvia, the cultivation of both species was tested in the LIFE REstore project. The aim of this work was to test into practice the establishment of highbush blueberry and large cranberry plantations in extracted peatlands, and to evaluate the advantages and disadvantages of this after-use scenario (see also Chapters 3, 4, 6.2.4).

Two cutaway peatlands were chosen as demo sites for the establishment of berry plantations. Highbush blueberry plantations were established in Līvbērze rural territory, Jelgava municipality, in the eastern part of Kaigu Mire, on land owned by SIA "Arosa R" (Figure 148). The company manages 117 ha of extracted peatlands. Highbush blueberries were planted in an area of 4.2 hectares. Large cranberry plantations were established in Ranka rural territory, Gulbene municipality, Kaudzīši Mire (Figure 148), in a territory where peat extraction has recently been completed, although peat extraction is still ongoing in a different part of the same land property. Cranberry plantation was established in a 3.4 ha area.

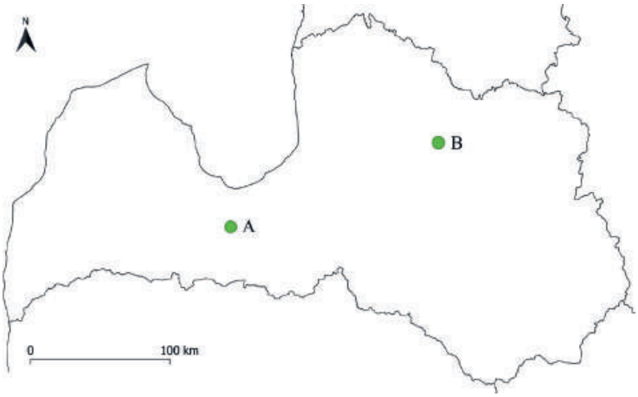

Figure 148. LIFE REstore berry plantation demo sites. Author of map: A. Priede.

The cultivation of highbush blueberries and large cranberries is well known and practised in several countries worldwide. However, this type of economic activity does not have a longstanding tradition in Latvia. Experimental cultivation of large cranberries was started before 1990 in some areas. Cultivation of highbush blueberries in extracted peatlands was started in 2003. Since 1995, the cultivation of large cranberries in Latvia has become a permanent sector of economic activity. The area size of large cranberry plantations is growing year by year (Maltenieks 2008).

Material and methods

Preparation and approval of reclamation design

Prior to the establishment of plantations and the earthworks, reclamation designs were developed for both demo sites. Work was planned in accordance to requirements of Cabinet Regulation No 570 of 21 August 2012, On the Procedure Regarding Extraction of Mineral Resources. Design sketches were approved by Building Boards of Jelgava and Gulbene municipalities.

Establishment of highbush blueberry plantations

Highbush blueberry plantations were established in the former peat extraction site in Kaigu Mire. Here, the thickness of residual peat ranged from 0.7 to 1.0 metres. The upper peat layer consisted of poorly decomposed to moderately decomposed raised bog cottongrass-*Sphagnum* peat and pine-cottongrass peat. Peat decomposition degree ranged from 14% to 25% (on average 20%), while the pH value varied between 4.5 and 5.0 (on average 4.7) (see Chapter 3.1).

Highbush blueberries were planted in the extracted peat fields which were located in the marginal area of the peatland and initially were considered as unsuitable for berry plants by landowner. During the peat extraction time, these margins were used to place the peat and remains of uncovered ancient trees. Before the establishment of berry plantations, these margins were used to place the excess material obtained during the field levelling. Over the years, these production fields were visually very different from the rest of the territory. However, the properties of peat were suitable for blueberries. There was sphagnum peat with a peat depth exceeding 0.5 m, pH value 2.7–5.0, and average groundwater table 0.35–0.55 metres. Groundwater table was appropriate for the establishment of highbush blueberry plantations, as the drainage systems in the field were well functioning and were properly maintained.

Prior to planting the berry plants, extensive surface preparation work was carried out. Peat surface was levelled up to the level of adjacent fields, to include it in the joint structure of fields. Removed excess material was transported away, and a smooth, even area was created. After the surface levelling, fields were milled to ensure their suitability for highbush blueberry plantations.

After ground preparation, mineral fertilizers were applied. Superphosphate (about 160 kg/ha) and a mixture of potassium magnesium oxide (160 kg/ha) were applied. Fertilizer doses were chosen after recommendations of the landowner M. Rudzāte based on her experience in growing highbush blueberries.

When the field was prepared, furrows were created. To create straight and parallel furrows, markings were placed at both ends and in the middle of furrow. Furrows were created with a bed shaper, with an elevation of 0.5 m and width of 0.7 m. The distance between the furrows was three metres.

After creating the furrows, berry plants were planted manually in the elevations. For every plant, a hole was made, in which a plant was placed, and the hole was backfilled. The distance between the berry plants was 1–1.2 metres. Plants were watered immediately after the planting. Precipitation water accumulated in pits at the edges of fields was used for watering.

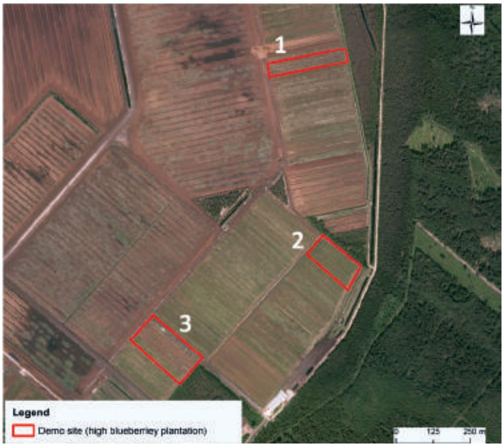

Figure 149. Highbush blueberry plantations – LIFE REstore demo sites – in Kaigu Mire. Map prepared by A. Rudusāne using the orthophotomap of 2013–2015, scale 1:10,000, © Latvian Geospatial Information Agency.

Highbush blueberries were planted in three fields (Figure 149). The first field was 170 m long and 70 m wide. Its area size was 1.2 hectares. Annual seedlings of highbush blueberries *Vaccinium corymbosum* 'Blue Blue' were planted. In total, 3275 seedlings were planted. The length of the second field was 200 m, width – 108 m, including the 24 m wide land road. The area size of the field (without road) was 1.8 hectares. Two-year-old *Vaccinium corymbosum* 'Reka' seedlings were planted, 4002 seedlings in total. The length of the third field was 263 m and the width was 44 metres. The area size of the field was 1.2 hectares. Two-year-old *Vaccinium corymbosum* 'Reka' seedlings were planted. The number of seedlings was 2500. Seedlings were planted from 12 to 16 June 2017. Planting material as purchased from nurseries in Poland.

Establishment of large cranberry plantation

Large cranberry plantation demo site was located in Kaudzīši Mire (Figure 150). Here, peat thickness varied from 0.1 to 0.5 metres. The results of site investigation (Anon. 2015) show that the entire upper layer of peat deposit in Kaudzīšu Mire consists of moderately to highly decomposed raised bog cotton grass-*Sphagnum* peat, but the deeper section – of pine-cottongrass peat. Peat decomposition degree ranges from 22% to 46% (30% on average), which indicates on moderately decomposed peat; the pH level ranges from 2.7 to 3.3 (2.9 on average). The territory was not exploited for five years after the peat extraction was completed. It started to overgrow with trees (mostly *Betula* spp.) and shrubs. Four fire-fighting ponds were located in the area adjacent to the peat extraction area. Water of these ponds was used for large cranberry watering. The area of large cranberry plantation demo site was 3.4 hectares.

Figure 150. Large cranberry plantation – LIFE REstore demo site – in Kaudzīšu Mire. Map prepared by A. Rudusāne using the orthophotomap of 2013–2015, scale 1:10,000, © Latvian Geospatial Information Agency.

First, vegetation and remains of stumps and roots were removed. Peat surface was smoothened, drains were cleaned. Drainage system was investigated, and concluded that it functions well. The average groundwater table was 0.35–0.5 m below the ground.

After the site preparation, peat was cultivated to a depth of 0.4 m; the whole field was treated with peat miller. For fertilization, superphosphate (about 100 kg/ha) and potassium magnesium oxide (100 kg/ha) were used. The fertilizer doses were chosen according to the recommendations given by J. Dūte following experience of berry plant growers.

Cranberry vines were obtained from adjacent large cranberry plantations and purchased from cranberry growers. Two varieties of large cranberries, *Vaccinium macrocarpon* 'Steevens' and 'Bergman', were planted. The total amount of planting material was 2 t/ha.

Large cranberry vines, approximately 10 cm long, were evenly distributed across the field. The 'Steevens' variety was planted in four former production fields, and the 'Bergman' variety – in three former production fields. Afterwards the entire field was processed with soil cultivator at a depth of 3 centimetres. The field was watered after planting. Planting was carried out in the spring of 2018.

Results and discussion

Highbush blueberries were planted in mid-June, 2017. The beginning of summer is not the preferable time for planting of berry plants because of the prolonged drought risk; the sun reaches its highest point and there is a risk of peat overheating, resulting in dying of seedlings. Excessive humidity is recommended for seedlings during the first weeks after planting until the first white roots develop, thus supporting the nutrient exchange between the plant and the soil (ZM 2011). The selection of demo sites and the development of reclamation design were delayed, so the best time for highbush blueberry planting was lost. Planting of highbush blueberries is recommended in late autumn. However, the summer of 2017 was one of the rainiest summers in recent years, and all seedlings survived and established. At the final stage of the project, it can be concluded that highbush blueberry plantations are developing well.

Large cranberry plantations were established in Kaudzīšu Mire in spring of 2018. At the beginning of 2018, the site was fully prepared. Planting was carried out from 18 to 25 May 2018 when the weather conditions were finally suitable for planting. In order to ensure suitable conditions for growing large cranberries, landowner installed a watering system. Water was previously accumulated in adjacent fire-fighting ponds which were established for peat extraction.

Highbush blueberries can be harvested in the third or fourth year after planting, therefore it is not possible to make full conclusions about the success of this reclamation type. However, none of the planted plants have withered away; seedlings are vigorous and grow well. Thus, it can be concluded that the planting of highbush blueberries for reclaiming the extracted peatland was successful.

In the first year after planting, the peat surface was mostly covered by large cranberry shoots. Large cranberries can be harvested in the fourth year after planting, therefore it is not possible to make full conclusions about the quality of reclamation immediately after the planting. However, already three months after the planting, seedlings produced new leaves, indicating on the development of new roots and on successful establishment. Similarly to highbush blueberries, it is important for large cranberries to ensure sufficient moisture during the first growing season, in order to promote the development of new roots. Although the summer of 2018 was very dry, the watering system ensured suitable moisture conditions.

Berry plantations (Figures 151, 152) is the most profitable after-use scenario for extracted peatlands, as found by LIFE REstore project team when developing the optimization model for sustainable management of areas affected by peat extraction (see Chapter 6.4). If plantations are properly managed, seedlings are well cared for and berries are harvested, the investments may pay off in 8 to 13 years. Out of the eight analysed types of degraded peatland after-use (see Chapter 6.2), also afforestation is financially profitable, though the payback period of this investment is longer.

Figure 151. Young highbush blueberry plantation. Photo: D. Siliņa.

Figure 152. Large cranberry plantation with surface irrigation system. Photo: D. Siliņa.

Results of the first year of greenhouse gases (GHG) measurements show that the establishment of berry plantations initially reduces GHG emissions if compared to unreclaimed peat extraction areas. However, in the long term (25 to 100 years), GHG emissions from berry plantations would be higher than those from abandoned, unreclaimed peat extraction areas. GHG emissions are also high due to fertilization prior to planting berry seedlings. Also later the plants need to be additionally fertilised in order to increase the yield. For more information on measurements of GHG on hydromorphic organic soils – see Chapter 3 of this book.

The values of ecosystem services provided by berry plantations in the former peat extraction areas are variable. The value of provisioning services was estimated as moderate (value in the indicator scale – 3), because the areas do not provide other provisioning services than berry yield. Among regulation and supporting services, berry plantations ensure high values of erosion control and water cycle regulation (value in the indicators scale – 4). However, other regulation and supporting services are not provided. The recreational value of such areas is low (value in the indicator scale – 1), though they have research and educational function (LIFE REstore 2017). More on ecosystem services – see Chapter 5.

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6.3.3. *Sphagnum* reintroduction demo site

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Laura Grīnberga, Andis Lazdiņš, Juris Nusbaums

Summary

To restore peat-forming mire vegetation in a cutaway peatland, reintroduction of *Sphagnum* and other plants of raised bog was carried out in the LIFE REstore demo site in the north-eastern part of Ķemeri Mire. Prior to *Sphagnum* reintroduction, suitable moisture conditions were created by removing the upper, highly decomposed peat layer, thus lowering the peat surface, and by filling in the nearby ditch. Due to prolonged drought in summer 2018, the success of *Sphagnum* establishment was low. However, a few months later survival of some patches of *Sphagnum* and other bog plants was observed. Hydrological and vegetation monitoring should be continued to evaluate the reintroduction success.

Introduction

After cessation of peat extraction, restoration of mire ecosystem with its key functions such as peat accumulation, carbon removals and biodiversity maintenance is highly recommended (Chapman et al. 2003; Renou-Wilson et al. 2019). This would at least partially compensate for the negative environmental impact caused by peat extraction. In long term, reintroduction of peat-forming vegetation would allow recovery of peat accumulation as well.

Rehabilitation of peatland ecosystems in cutaway areas can be carried out in several ways which depend on the degree of degradation and site conditions. Rewetting is the most commonly used approach. If wetland conditions are successfully restored, peat-forming vegetation and peatland ecosystem functions, such as carbon removals, are able to recover. Successful peatland restoration is not possible in sites with inappropriate water table, for example if peat extraction is being continued in the nearby areas, and therefore a drainage system is maintained. It should be taken into account that restoration of the pre-existing mire conditions, vegetation and ecosystem functions may take several decades or even hundreds of years. Moreover, restoration success may be significantly influenced by other conditions, such as the area of peatland and the distance to the nearest donor areas of plant propagules (natural or near-natural mires).

In Latvia, reintroduction of mire plants is a new, little tested solution. Its purpose is to accelerate recovery of peat-forming vegetation in cutaway peatlands, which may result in recovery of functioning wetland ecosystem. Broader application of this method dates back to Canada in the 1990s. Here, the technique was developed, and a large number of scientific studies (e.g. Ferland, Rochefort 1997; González, Rochefort 2014) and guidelines for application of this method (Quinty, Rochefort 2003) have been published. Canadian researchers point out that *Sphagnum* is the keystone genus for mire habitat restoration (Rochefort 2000). *Sphagnum* mosses have been reintroduced also in some European countries, for example, in Estonia (Robroek et al. 2009; Karofeld et al. 2016), Ireland, the UK (Rosenburgh 2015), and Germany (Poschlod et al. 2007) with varying success. In small areas, experimental cultivation of *Sphagnum* in cutaway peatlands has been tested also in Latvia: in Ķēviešu Mire (Mālpils municipality) and Kaigu Mire (Kalnciems municipality). However, the purpose here was *Sphagnum* cultivation for the testing of paludiculture technique and adoption of this method to Latvian conditions.

One of the objectives of the LIFE REstore project was to test several types of reclamation, including rehabilitation of peatland ecosystem by reintroducing species characteristic to raised bogs to facilitate recovery of peatland functions including peat formation. The aim of reintroduction was to test this method in a possibly large area according to the available funding. As a test area, an extracted peatland in Ķemeri Mire was chosen where vegetation did not regenerate itself for a long term. The main tasks of the project was to estimate the amount of work necessary, costs and resources needed, as well as to assess the change in greenhouse gas (GHG) emissions and ecosystem services after rehabilitation measures.

Material and methods

Demo site before rehabilitation

The *Sphagnum* reintroduction demo site is located on the north-eastern edge of Ķemeri Mire (Figure 153), in Ķemeri National Park. In this particular peat field, peat extraction was discontinued more than 30 years ago; however, since then, peat-forming vegetation had not recovered. Initially, the peat was extracted by block-cutting in Ķemeri Mire. Later, the marginal areas were used for milled peat production (EnviroEnGen 2017). A rather thick layer of peat was left in the milling fields, as peat extraction in Ķemeri Mire was discontinued in the early 1980s (Strazds, Ķuze (eds.) 2006).

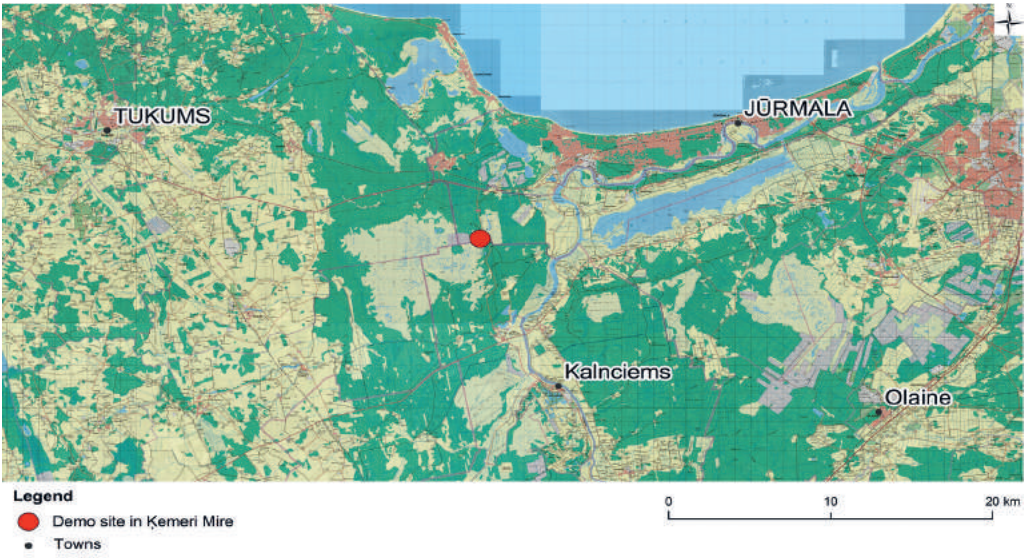

Figure 153. Location of the demo site. Map prepared by A. Rudusāne using the satellite map of Republic of Latvia on a scale of 1:50 000. Map base: © Latvian Geospatial Information Agency.

Figure 154. Demo site before rehabilitation in 2016. Photo: M. Pakalne.

The area of demo site was dominated by bare, exposed peat with sparse, species-poor vegetation. The dominating species were *Eriophorum vaginatum*, *Calluna vulgaris*, *Polytrichum commune*, *P. juniperinum*, *Betula pubescens*, *Pinus sylvestris* (Figure 154). Invasive moss species *Campylopus introflexus* was found at the edge of the peat field, indicating on peatland degradation. Small patches of *Sphagnum* and other bog species were found only near the ditches. Recovery of peat-forming vegetation was hindered by low and highly fluctuating groundwater table.

In the demo site, 3–3.5 m thick residual peat deposit was found. The deeper layer (at 2.10–3.5 m depth) consisted of transitional mire peat and fen peat, with a pH value of up to 4.95. The upper layer (down to the depth of 1 m) was composed of raised bog peat (poorly to moderately decomposed *Sphagnum fuscum* peat). pH value of the upper layer varied from 4.1 to 4.3 (EnviroGenTech 2017) which is not characteristic for intact raised bogs with more acidic environment. More on peat properties in the demo site: see Chapter 4.1. Due to low water table the peat surface was highly decomposed.

In total the area available for the experiment occupied 4.4 ha, consisting of six former peat production fields of various lengths (Figure 155). The available funding was not sufficient to carry out the reintroduction experiment in the entire area, thus only one of the former production fields was selected. The basic requirement for choosing this demo site was its easy accessibility by vehicles needed for preparation of the surface and transportation of planting material. The area also had to be sufficiently homogeneous, which eases interpretation of the results.

After cessation of peat extraction, the drains were not filled in and were still functioning. All of them were connected to the larger ditch downstream at the eastern edge of the peat fields. In 2006, the surrounding area (more than 100 ha) of cutaway peatland, both block-cut and milled areas, was rewetted within another earlier LIFE project. That time the ditches were blocked and other hydrotechnical measures taken to raise the water table (Ķuze, Priede 2008). However, it did not result in water level rise in the demo site later chosen by LIFE REstore project, because the surface was gently sloping and the raise of water table affected only the eastern edge of the former peat milling field. The altitude above the sea level in west-east direction changed by 0.6 m (Figure 155).

Figure 155. The entire former peat milling field and demo site.
Map prepared by A. Rudusāne using the orthophotomap of 2013–2015, scale 1:10 000. © Latvian Geospatial Information Agency.

Planning and work coordination

The preparation stage took almost two years, and it included site investigation and modelling, planning, and coordination of works. Planning of works started with the evaluation of site conditions and their suitability for reintroduction of peat-forming vegetation (*Sphagnum* planting). The investigation included studies of peat stratigraphy, which provided important information on site suitability for species of raised bog (see Chapter 4.1), as well as hydrogeological modelling to evaluate the possibility to raise the water table to restore appropriate hydrological conditions (see Chapter 4.3). The research results were used for developing the reclamation design (EnviroEnGen 2017).

Peat extraction in this area was ceased in the Soviet period, therefore, according to the current legislation, development of reclamation design and its approval in building board of the local municipality was necessary. Development of reclamation design included: topographic survey; cross-sectional analysis; evaluation of hydrological regime; development of technical solutions and their representation in technical drawings, as well as calculation of the character and volume of works. The prepared reclamation design was submitted to Building Board of Babīte Municipality and was approved in November 2017. The proposed reclamation did not include any construction work in terms of the

Construction Law, therefore preparation of the building design was not necessary (EnviroEnGen 2017). Considering that the demo site is located in the nature reserve zone of Ķemeri National Park, the relevant nature protection plan (CarlBro 2002) was taken into account. In the particular area, it recommended rehabilitation of peatland ecosystem. This meant that *Sphagnum* reintroduction experiment did not conflict with the actions proposed in the nature management plan. The land manager Nature Conservation Agency was contracting authority for the earthworks.

Before the experiment, the surface was gentle-sloping and varied from 9.0 to 9.3 m above the sea level (Figure 156). It was decided to level the surface in the entire demo site to about 8.6 m above the sea level. This was below the winter groundwater table, but above the summer level recorded in 2017. At this level, the area could be temporarily flooded at high water levels but remain wet at low groundwater table.

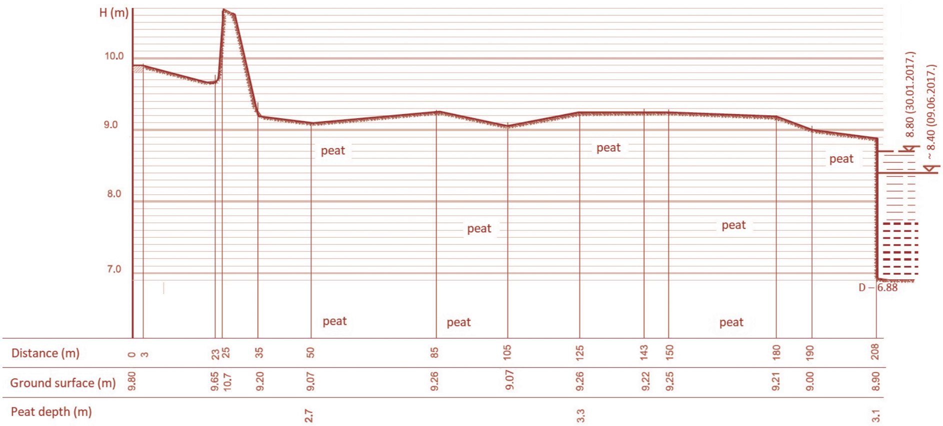

Figure 156. Surface character in west-east direction, before surface levelling. Sketch by J. Nusbaums.

In order to increase the establishment and survival success of peat-forming vegetation and the potential of acrotelm formation, the highly decomposed upper layer of peat must be removed and the surface levelled to reduce the surface gradient before reintroduction of *Sphagnum* mosses. Thus, the surface would be equal to the recorded water table in summer. Building of terraces was considered inappropriate, because the surface gradient and the entire area of the demo site were too small.

Other measures aimed at raising the groundwater table were not proposed, because the demo site was located in a protected nature area, but all groundwater modification works are considered as construction works according to national legislation. The required environmental impact assessment in this case would take too much time and require additional funding.

Implementation of the experiment

After site selection and development of reclamation design, creation of conditions suitable for peat-forming vegetation was necessary. At first, excessive vegetation was removed. Then, one of the drains was blocked at the northern edge of experimental field to pump out the water and allow surface levelling. Surface was levelled towards the northern and southern edges. It was calculated that peat layer should be levelled by removing on average 0.42–0.62 m of peat, thus relocating ca. 1500 m^3 of peat. As a result, a flat area of 3200 m^2 area was created. In total the demo site covered 4500 m^2.

The removed peat was placed around the perimeter of experimental field, creating a berm. In the particular situation, there was no other solution where to locate the peat. This way, the drain at the northern edge of the experimental field was completely filled in. The ditch at the southern edge was preserved to drain the excess water. At the northern and southern edges, the berms were approximately 1.2 m high. At western and eastern edges, berms were narrower and lower with the average height of 0.5 m, width at the base – 3 m, width at the top – about 1 m (EnviroEnGen 2017).

However, the creation of berms around the experimental field had an adverse effect – the territory would be flooded for a long time in case of high precipitation which might create unsuitable conditions for *Sphagnum* growth. To prevent excess water, two pipes (with gradient 5%) were located at the southern edge of the field. The pipes were 3.0 m long, 0.15 m in diameter. They were placed next to each other with a 0.15 m gap and covered with peat (0.5 m thick layer). The pipes were located 0.05 m above the field surface to allow slight increase of water level and temporary flooding of the area.

After the site preparation, the demo site was divided into four 30 x 35 m experimental plots (Figure 157) where *Sphagnum* mosses were planted. In plots No. 4, 5, and 6, the upper peat layer was removed and the surface was smoothened. No measures were applied in plot No. 7 except for *Sphagnum* planting.

Figure 157. Performed works, location of experimental plots and planted species at demo site. Map prepared by A. Rudusāne, using orthophotomap of 2013–2015, scale 1:10 000.
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1	Reference area (no measures applied). Monitoring was commenced in 2017 (13 vegetation sampling plots established).
2	Buffer zone (20 m wide), no measures applied.
3	Buffer zone along the ditch with wet peat; border between the demo site and old block-cut area. No measures applied.
4	The upper layer of peat was removed and surface level smoothened. In May 2018, hummock *Sphagnum* species* and *Sphagnum* species of bog pools** were planted and covered with straw.
5	The upper layer of peat was removed and surface level smoothened. In May 2018, hummock *Sphagnum* species* were planted and covered with straw.
6	The upper layer of peat was removed and surface level smoothened. In May 2018, hummock *Sphagnum* species* were planted together with other bog species (*Andromeda polifolia*, Drosera spp., *Sphagnum* species of bog pools**) (up to 30% of total cover), and covered with straw. In September 2018, after removal of peat surface, in two extra plots of size 2 x 2 m *Sphagnum* material was introduced. Dam of peat and planks was constructed on the adjacent field ditch.
7	Unsorted Sphagnum mosses were planted without removing the upper peat layer, covered with straw.

Hummock *Sphagnum* species: *Sphagnum magellanicum*, *S. fuscum*, *S. rubellum*,
** *Sphagnum* species of bog pools: *Sphagnum cuspidatum*.

Sphagnum planting material (sods) was harvested manually in Drabiņu Mire (relatively undisturbed raised bog close to the demo site) on May 17, 2018 (Figure 158). The collected sods consisted mainly of *Sphagnum*, though contained also living fragments of other bog plants. The collected material was packed into bags and transported to the demo site.

Figure 158. Harvesting of *Sphagnum* and other bog plants in Drabiņu Mire. Photo: M. Pakalne.

Figure 159. *Sphagnum* planting. Photo: M. Pakalne.

Figure 160. Straw cover created after *Sphagnum* planting. Photo: M. Pakalne.

The next day after the *Sphagnum* harvest, on May 18, 2018, *Sphagnum* material was planted (Figure 159, 160), with 62 volunteers participating. In total, 2200 kg of *Sphagnum* mosses were planted in an area of 4500 m^2. It was chosen to plant *Sphagnum* clusters instead of spreading the *Sphagnum* fragments across the areas, as suggested, for example, in the Canadian method (Quinty, Rochefort 2003). Although *Sphagnum* mosses can develop from small fragments, they are sensitive to drought, and small fragments cannot accumulate water as larger *Sphagnum* clusters. Prior to planting, *Sphagnum* were sorted by dominant species and divided into small clusters (5 x 5 cm).

These *Sphagnum* groups were evenly planted, about 0.5 m from each other. In some places, fragments of mire plants were spread across the peat surface.

In the experimental plot No 4, hummock species (*Sphagnum magellanicum, S. fuscum, S. rubellum*) and species of bog pools (*S. cuspidatum*) were planted. In plot No 6, *Sphagnum magellanicum, S. fuscum, S. rubellum*; in plot No 7, *Sphagnum magellanicum, S. fuscum, S. rubellum* and some other bog species, such as *Andromeda polifolia*, *Drosera rotundifolia, Calluna vulgaris* were introduced. In plot No 7, all abovementioned unsorted *Sphagnum* species were planted.

After planting, plots No 4, 5, 6, and 7 were covered with straw, in order to protect plants from sun exposure and drying out. Approximately 1500 kg of straw were spread evenly across the area. The summer of 2018 was extremely dry. Therefore, during the first vegetation season the *Sphagnum* plantings were watered. Water was taken from the neighbouring old block-cut peatland (for former raised bog) – pumped from the ditch bordering with the demo site. 150 m long fire hose was used for watering. The chemical properties of the water were not tested. However, according to the environmental conditions and vegetation character, the water properties were most likely typical for raised bog environment, with low pH value and low conductivity. During each watering event, the area was watered for 1.5 hours. Regular monitoring of *Sphagnum* vitality and site moisture conditions was carried out throughout the summer 2018. The frequency of watering was determined by weather conditions and site condition. During the first vegetation season, inspectors of Nature Conservation Agency surveyed the territory every three days, assessing the moisture condition, recording the observed condition in a simple form, and deciding whether watering is necessary.

In autumn 2018, after the extremely dry summer, *Sphagnum* planting experiment was supplemented with small extra plots (Figure 157). Two 2 x 2 m experimental plots were established at various depths (0.30 m and 0.15 m), after removing the upper peat layer, so that the surface was close to the groundwater table. Similarly as before, the planting material was harvested in adjacent intact part of Ķemeri Mire. *Sphagnum magellanicum* was the dominating species in the collected material, but also other raised bog plant species were present. *Sphagnum* mosses were planted by hand and covered with straw.

An overview of all the work carried out in Ķemeri Mire demo site is shown in Figure 161.

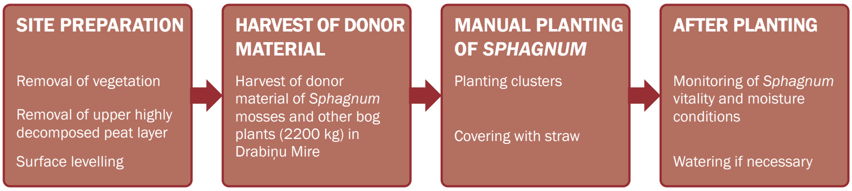

Figure 161. Works carried out in the demo site.

Monitoring

Monitoring of groundwater table

Groundwater table was monitored to follow the changes in hydrological condition of demo site. Eight piezometers were established at demo site and nearby (Figure 162, Appendix 5). One of the eight piezometers (U3-A) was equipped with a filter interval on sandy sediments under the peat layer to control the vertical water exchange between soil horizons. The other seven piezometers were equipped with filter intervals in peat layer. The borehole construction of all piezometers was similar (except for U3-A) – a 2.5–3 m long 40 mm diameter PVC tube, ~0.5–0.7 m section is left above the ground. Its lower part was equipped with a 1 m long perforated filter. The tube was sealed from both the bottom and the top with 40 mm diameter PVC caps. The lower cap was glued, whereas the upper cap could be opened. To prevent any movement of the tube, it was supported with a metal rod where the borehole does not reach the mineral ground, as shown in Figure 163.

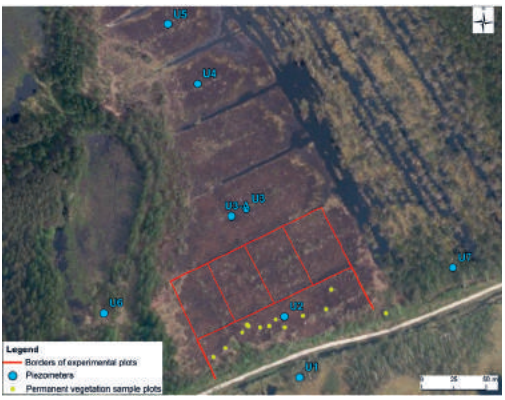

Figure 162. Location of piezometers and vegetation plots in the demo site. Map prepared by A. Rudusāne using the orthophoto map of 2013–2015, scale 1:10 000.
© Latvian Geospatial Information Agency.

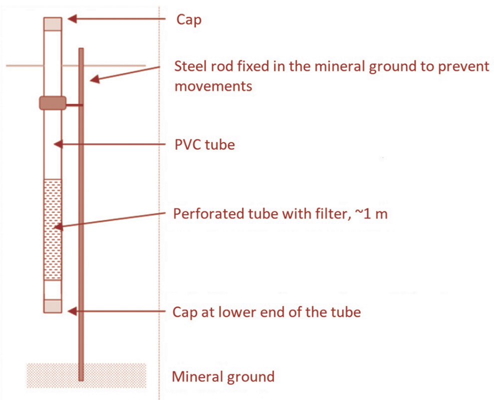

Figure 163. Construction of piezometer with a fixed rod to prevent movement. Drawing: Dēliņa (2014).

Measuring of water table was undertaken manually with Electric Contact Meter *Seba KLL Mini,* 10 m. The equipment consists of a smooth measuring tape with a sensing device at the end. By placing the measuring tape measure into the tube and slowly lowering it, the sensor contacts the water, gives a sound signal, and result can be read. Measurements can also be made with a simple smooth measuring tape with a counterweight. The measuring tape is immersed in the tube and the measurement can be recorded when the contact with water is heard. During the first measurement it is necessary to measure the length of the pipe above the ground surface. The groundwater table must be measured in all wells, and the length of each pipe above the ground must be subtracted from these measurements, resulting in a groundwater table from the ground surface. Groundwater tables were measured approximately once a month.

For the interpretation of changes in groundwater table, the average amount of rainfall from the Latvian Environment, Geology and Meteorology Centre (LEGMC) database was used for the period from July 2018 to February 2019. Data were taken from the nearest meteorological station (Kalnciems, ~15 km from the demo site).

Vegetation monitoring

In 2017, 13 permanent vegetation sample plots were established in a buffer zone of the demo site, before reintroduction of *Sphagnum*. In the future, monitoring will provide a possibility to compare vegetation development in *Sphagnum* reintroduction area and the control plots where no measures were applied. In 1 x 1 m square-shaped plots, all species of vascular plants and mosses were recorded, and their cover in percentage was estimated by eye. Coordinates (LKS-92 system) were recorded for each sample plot (Figure 163, Appendix 5). All sample plots were photographed. In 2019, such plots will be established in the *Sphagnum* reintroduction area to observe development of vegetation.

Results and discussion

Preliminary results

Good-quality planting material was collected, and the peat surface was moist during planting. In autumn 2018, all reintroduced *Sphagnum* species (*Sphagnum magellanicum, S. fuscum, S. rubellum, S. cuspidatum*) could be found in the experimental plots, although in much smaller quantity than planted. Large proportion of the planted *Sphagnum* mosses had died, and only small clumps survived (Figure 164–166). However, it must be taken into account that less than one year is not enough for the unbiased evaluation of the results.

In control plots outside the experimental plots, 15 plant species were recorded. Among them, the most common were *Calluna vulgaris*, *Eriophorum vaginatum*, *Polytrichum commune*, *Pinus sylvestris*, *Betula pendula*, *B. pubescens*. Only in one sample plot, species indicating wet conditions – *Drosera rotundifolia*, *Rhynchospora alba*, *Trichophorum albinum*, were recorded, as well as invasive moss species *Campylopus introflexus*. *Sphagnum* was not recorded in any of the sample plots. Overall, the vegetation was species-poor, typical for dry cutaway peat fields abandoned for several decades.

Figure 164. *Sphagnum cuspidatum* survived under the straw cover, September 2018. Photo: M. Pakalne.

Figure 165. Some characteristic species of raised bogs: *Sphagnum magellanicum, Drosera rotundifolia, Oxycoccus palustris* established under the straw cover. September 2018. Photo: M. Pakalne.

Figure 166. *Sphagnum cuspidatum, S. rubellum* and *Drosera rotundifolia* survived under the straw cover in a shallow, wet depression, September 2018. Photo: M. Pakalne.

The demo site in Ķemeri Mire can be considered as a complicated area for rehabilitation of mire ecosystem. This was determined by a number of factors which directly influenced *Sphagnum* establishment success. Firstly, reintroduction was influenced by site topography. High water table is crucial for *Sphagnum* establishment. In the demo site, slope gradient in the west-east direction varied within a range of 0.6 m. Creation of even moisture conditions on the gentle slope was complicated, and modification of the surface was necessary.

In the demo site, taking into account the relief and groundwater table (measured in summer and winter before implementing earthworks), the surface was levelled down to 8.60 metres. The results of hydrogeological modelling (Chapter 4.3) showed that probably sufficiently high groundwater table could not be achieved, thus additional water supply may be necessary. This was also proved in practice – in the dry summer after *Sphagnum* reintroduction, extra watering was necessary.

Secondly, there are several ditches close to experimental plots. Within the LIFE REstore project, one of the drains was filled in. Perhaps this was not sufficient for raising the groundwater table and reaching appropriate conditions for peat-forming vegetation. Nevertheless, monitoring over a longer period than one year is necessary.

Thirdly, meteorological conditions may play a very important role in survival of *Sphagnum* and establishment of peat-forming vegetation (Priede (ed.) 2017). Raised bogs are fed by precipitation, so they are directly related to precipitation and evapotranspiration. Increased precipitation creates favourable conditions for mire development, but rise of the temperature increases evapotranspiration and desiccation of mire surface. Prolonged vegetation period and low amount of precipitation results in moisture deficiency. In this case, prolonged drought unfavourably affected survival of *Sphagnum*.

According to LEGMC, in June 2018, the highest air temperature record was exceeded in six observation stations. July 2018 was the third warmest July in the history of observations (since 1924). In July, several maximum air temperature records were achieved in Dobele station (meteorological station which is the closest to the demo site where air temperature and precipitation are being measured) reaching +30.7oC. The average air temperature deviation from the national climate normal in July at Dobele station was 2.8 oC. In all summer months of 2018, the average air temperature exceeded the average trend of air temperature in the country. It is likely that the very warm, dry summer of 2018 caused increased evapotranspiration and consequently worsened establishment of *Sphagnum* in the demo site.

There was also low rainfall in late spring and summer of 2018. May 2018 was the third driest month in the 21st century. The total rainfall in Latvia was 51% below the monthly climate normal. In Dobele station, the precipitation deviation from the monthly climate normal in May 2018 was -65% and in June -50%. July 2018 was the second driest July in the 21st century. The total rainfall in Latvia was 31% below the climate normal in July. In Dobele station, deviation from the climate normal in July 2018 was -31%. Insufficient precipitation in May, June and July 2018 could have definitely had a negative impact on *Sphagnum* establishment in the demo site.

Observations during the first year show that groundwater table at the demo site was too low for peat-forming vegetation. In the summer months that followed *Sphagnum* reintroduction, the groundwater table was 48–57 cm below the ground (the lowest observed water table was 114 cm) (Figure 167). The amount of precipitation did not increase significantly by the end of 2018. However, groundwater table gradually increased in autumn and winter likely due to reduced evapotranspiration. No clear correlation with rainfall has been observed. However, the monitoring results reflect a short period of time, therefore a linear relationship could not be expected.

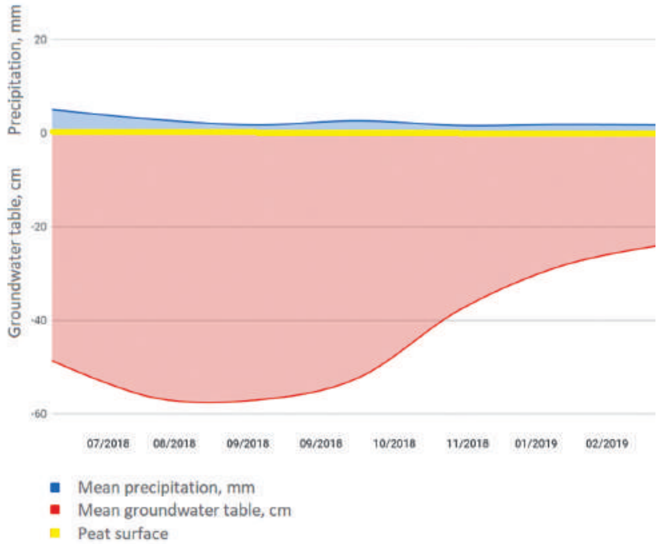

Figure 167. Mean groundwater table in relation to mean rainfall from July 2018 to February 2019 at the demo site.

The influence of extreme drought was partly prevented by straw cover, which allowed the peat surface to maintain moisture longer. Following a method adopted in Canada (Quinty, Rochefort 2003), approximately 80% straw coverage was created. If this is not done properly and if some other mistakes (e.g. too low water table) are done, the revegetation success may be low, as shown, for example, by the experience in Viru Mire in Estonia (Karofeld et al. 2015). At the demo site in Ķemeri Mire, we assume that the straw cover was created properly, whereas the drought might be the ruling factor that affected the result, at least during the first season.

The experiment carried out in Ķemeri Mire is essential for evaluating the reintroduction possibilities of *Sphagnum* and other mire plants in Latvian climate conditions. Rehabilitation of cutaway peatlands takes a long time, thus the outcome of the *Sphagnum* reintroduction experiment, either success or failure, could be properly assessed only a few years later. Regular vegetation and groundwater table monitoring must be continued.

Chances and risks related with Sphagnum reintroduction

Re-establishment of peat-forming vegetation is the only way to at least partially compensate the loss of peatland ecosystems due to peat extraction. Reintroduction of peat-forming vegetation (either planting of *Sphagnum* "clumps" or spreading of *Sphagnum* fragments) is a suitable solution for rehabilitation of degraded peatlands. Reintroduction of mire plants is not a "must" in all areas, as some of them are capable to recover if appropriate hydrological conditions are re-established. Reintroduction promotes faster and more successful recovery of mire vegetation. Peat-forming vegetation is essential for recovery of peatland ecosystem functions, including accumulation of peat and carbon sequestration.

When reintroducing mire plants, most commonly *Sphagnum*, a number of conditions must be met. The most important one is to ensure a high water table, which on annual basis should be approximately in the level of peat surface (Quinty, Rochefort 2003). This is one of the prerequisites for establishment and survival of *Sphagnum* mosses and other mire plants (Hayward, Clymo 1982). Dry peatlands with low and highly fluctuating water tables are not suitable for the development of peat-forming vegetation. In most of such places, the establishment of certain mire plants (mainly species that tolerate large water table fluctuations) can be observed, but not a complete recovery of peat-forming vegetation and hence the peatland functions. If appropriate water table is not restored, the upper layer of peat remains dry and survival of plants is very low (Salonen 1987; Price 1996). The growth and survival of seedlings is also hindered by extreme conditions on peat surface, such as heating up and erosion (Quinty, Rochefort 2003). Such a situation may last for years, as it could be observed also in LIFE REstore demo site in Ķemeri Mire.

Studies in some other countries (Lode et al. 2010; Zajac et al. 2018) show that the establishment of peat-forming vegetation may take several decades. Even in cases when rewetting is properly carried out (Bonn et al. 2014; Nishimura, Tsuyuzaki 2014), it is not always possible to predict the development of vegetation. *Sphagnum* mosses are the main producers of bog peat, therefore they are usually considered as target species (Rochefort 2000). However, *Sphagnum* and other raised bog species can survive only in acidic, nutrient-poor environment. This means that *Sphagnum* planting is meaningful and can lead to successful outcome only in sites with residual raised bog peat. In peat of transition mires and fens, species occurring in similar sites (e.g. sedges, ruches, brown mosses) can be planted. However, there is no such experience in Latvia yet and there is still little experience elsewhere in the world (e.g. in Canada – Rochefort et al. 2016; Gagnon et al. 2018), especially considering the large variety of conditions in cutaway peatlands with residual fen peat (see Chapter 4.4).

If raising of water table is not possible, reintroduction of *Sphagnum* or other mire plants is inappropriate means of reclamation. It is also important to apply other measures such as: removal of highly decomposed peat layer (if appropriate); choosing proper season for planting; establishment of straw or similar material cover ("shelter"), so that the reintroduced plants do not die soon. In Latvia, the optimal planting time is the first half of autumn, when there is a relatively large probability of large amount of precipitation that could follow the works, or early spring soon after snowmelt. The experience of LIFE REstore experiment show that planting in early summer is associated with a high risk that subsequent summer may be dry and a large proportion of the *Sphagnum* may not survive.

Impact of rehabilitation of cutaway peatland on greenhouse gas emissions

Rehabilitation (including rewetting) of cutaway peatlands and reintroduction of peat-forming vegetation is important for the reduction of greenhouse gas (GHG) emissions. In the demo site in Ķemeri Mire, 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands (Hiraishi et al. (eds.) 2014) was used. According to the default GHG emission factors, the reduction of GHG emissions by rewetting a cutaway peatland, mainly due to the reduction of CO_2 emissions, is 4,3 t CO_2 eq. per year (9.4 t CO_2 eq. ha^{-1} per year). By using the emission factors acquired within the LIFE REstore project, the actual GHG emissions will not decrease after rehabilitation, mainly due to significant increase in CH_4 emissions, as the site was rewetted. However, according to the IPCC 2006 Guidelines, GHG emissions from natural ecosystems should not be counted. Therefore, in the project impact calculations for non-commercial after-use scenarios, including the demo site in Ķemeri Mire, it is assumed that GHG emission reduction corresponds to GHG emissions at status quo. According to measurements by LIFE REstore project team, the GHG emissions from the *Sphagnum* reintroduction area in Ķemeri Mire correspond to 4.1 t CO_2 eq. per year (8.9 t CO_2 ha^{-1} per year) which is considered to be a reduction in GHG emissions resulting from rehabilitation measures.

Impact of rehabilitation of cutaway peatland on ecosystem services

Evaluation of ecosystem services provided by the demo site in Ķemeri Mire lead to a conclusion that rehabilitation will increase the value of regulatory, provisioning and cultural services over the next years. Soil capability to bind and accumulate nutrients and importance for biodiversity will rise. Rehabilitation will enhance the site suitability for watching birds and other wildlife, thus the cultural and educational role of the area will increase. More on the assessment of ecosystem services – in Chapter 5.

Conclusions

- ✔ In May 2018, during reintroduction of *Sphagnum*, the conditions in the demo site were appropriate for establishing peat-forming vegetation. However, after the first season, the survival and establishment success was low. This was significantly affected by the extremely dry summer of 2018. It is likely that *Sphagnum* establishment would be more successful if planting would be carried out in early autumn, when more precipitation is likely to occur after planting. *Sphagnum* mosses are able to grow throughout the snowless season, so the initial "stabilization" might happen in the following autumn months and continue in spring. Alternatively, planting could also be done in early spring soon after snowmelt. Though it is too early to assess the results, the experience of LIFE REstore suggests that late spring and early summer are not the optimal planting seasons in Latvia due to possible summer drought.
- ✔ Appropriate water table is crucial for successful peatland rehabilitation. Creating optimal moisture conditions by only removing the upper peat layer is not the best solution and it could only be done in small areas with highly decomposed peat surface abandoned for a long time. If removal of upper peat layer is planned, its placement possibilities must be considered. Conditions for *Sphagnum* planting should preferably be established as soon as possible, preferably within a year after cessation of peat extraction. Then removal of upper peat layer is not necessary (it applies only to areas abandoned for a long time).
- ✔ To assess the establishment success of peat-forming vegetation, monitoring of groundwater and vegetation must be continued at the demo site. It is also recommended to continue GHG measurements.

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Annex 5. Coordinates of vegetation monitoring sample plots and piezometers (LKS-92 coordinate system)

No of vegetation monitoring sample plot	X	Y	No of piezometer	X	Y
1.	471051	306046	U1	471117	306030
2.	471060	306053	U2	471105	306077
3.	471073	306065	U3	471076	306160
4.	471077	306071	U3A	471064	306154
5.	471078	306070	U4	471038	306256
6.	471087	306069	U5	471016	306302
7.	471094	306070	U6	470966	306079
8.	471099	306075	U7	471235	306115
9.	471106	306069			
10.	471120	306078			
11.	471138	306083			
12.	471142	306098			
13.	471184	306080			

6.3.4. Restoration of drained peatland in Lauga Mire Nature Reserve

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Summary

During LIFE REstore project, planning and implementation of bog restoration (rewetting of drained raised bog) was carried out in Lauga Mire Nature Reserve. To select appropriate restoration measures and improve the condition of the raised bog neighbouring to peat extraction fields, a nature protection plan was developed. It included inventory of habitats and species, management planning, and modelling of the influence of the proposed blocking of ditches. Nature protection plan was developed in accordance with procedures specified in the national legislation. For the first time in Latvia, evaluation of ecosystem services was included in nature protection plan. The plan was developed for a 12-year period (2017–2029). During development of the plan, representatives of the responsible state and municipal authorities and landowners were involved in discussing the document and the proposed actions. This significantly improved the communication among stakeholders concerning planning and implementation of restoration works, as well as eased approval of the planned activities.

After approving the nature protection plan, construction design for three dams on drainage ditches was developed and approved. Dams were built in November 2018. They serve as a barrier for holding the outflowing water within the bog and help to raise the water table. In long term, an appropriate hydrological regime is the most important condition for the conservation of mire ecosystems.

Introduction

Lauga Mire Nature Reserve was established in 1999. It is located in north-west part of Vidzeme Region, in Vidriži rural territory of Limbaži municipality, and in Lēdurga rural territory of Krimulda municipality (Figure 168). The total area of the mire is 1876 hectares. The nature reserve includes its central part –740 hectares.

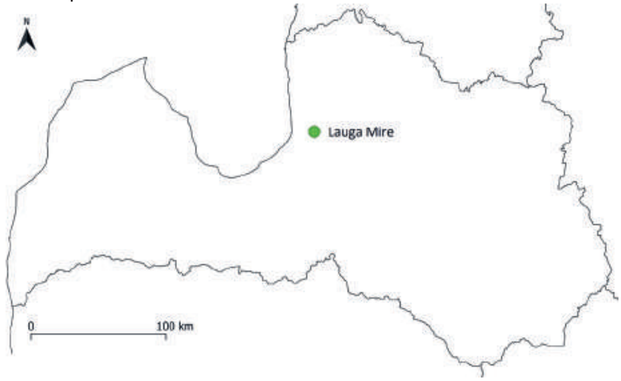

Figure 168. Location of Lauga Mire Nature Reserve. Author of map: A. Priede.

In 2005, after Latvia's accession to the European Union (EU), Lauga Mire Nature Reserve was designated as Natura 2000 site, with amendments to the Law On Specially Protected Nature Territories. The area is designated as Natura 2000 site (SAC[56]) that is important for protection of the following habitat types listed in the Annex I of the Habitats Directive[57]: 7110* *Active raised bogs* (Figure 169); 7120 *Degraded raised bogs still capable of natural regeneration* (Figure 170); 91D0* *Bog woodland*; 3160 *Natural dystrophic lakes and ponds*; 9010* *Western Taiga*. The largest area within the nature reserve is covered by active raised bog.

In the 1960s, the western part of Lauga Mire was drained, and peat extraction was commenced. Višezers Lake in mire central part was connected with the ditch network, thus the lake water level was lowered by 1.0–1.5 metres. Since most of the raised bog lies within the catchment of Višezers Lake (see Chapter 4.3), drainage had a deteriorating effect, resulting in raised bog degradation over a large area. Studies of historical maps suggest that before draining Lauga Mire has been an open, almost treeless raised bog. During the last few decades, the bog has largely overgrown with pines (Freimane (ed.) 2017).

Figure 169. Intact active raised bog in Lauga Mire Nature Reserve. Photo: M. Pakalne.

Figure 170. Ditch draining the degraded part of Lauga Mire close to the peat extraction fields. Photo: M. Pakalne.

56 Special Areas of Conservation (SACs) are designated under the Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora (Habitats Directive); SACs aim to preserve natural and semi-natural habitats which are interesting for their rarity and their primordial and ecological role.

57 Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora.

In order to restore degraded peatland ecosystems, it is highly important to prevent the drainage impact by reducing or completely eliminating the influence of ditches, by raising the water table, and by reducing the water table fluctuations (Priede (ed.) 2017). Drainage causes compaction and increased decomposition of the upper peat layer, as well as changes in vegetation leading to degradation of peat-forming vegetation that is being replaced by trees and dwarf shrubs. In case of severe drainage, the peat formation process is halted. These signs of bog degradation in drained areas were also observed in Lauga Mire in areas adjacent to peat extraction fields. Therefore, it was selected as LIFE REstore project demo site where rewetting of a raised bog affected by the adjacent peat extraction fields and related drainage was carried out.

The planning stage included initial environmental impact assessment and planning of restoration activities, development of nature protection plan, preparation and approval of documents related to restoration measures. This chapter gives an overview on activities of LIFE REstore project in Lauga Mire Nature Reserve.

Development of nature protection plan

The purpose of the nature protection plan is to match the interests of nature conservation, the use of natural resources, regional development and other interests in a way that conserves biodiversity of the particular area. Although the status of a protected nature territory for Lauga Mire has already been established in 1999, the area did not have a nature protection plan. In order to plan restoration activities to be implemented by LIFE REstore project, as well as to evaluate the necessity of other nature protection and restoration measures in the nature reserve, a nature protection plan was developed. This included a comprehensive assessment of habitats and species present in a territory, as well as the justification for the necessary management. In addition, the plan includes an assessment of ecosystem services –such approach has been carried out for the first time in Latvia as part of the nature protection plan. The assessment of ecosystem services allows comparing various land cover types and their potential to provide regulation, provisioning and cultural services (see Chapter 5).

Nature protection plan was developed in accordance with requirements set in the Cabinet Regulation No 686 of October 9, 2007, On the Content of and Procedure Regarding the Elaboration of Nature Protection Plan for Specially Protected Nature Territory. In the early stage, an informative meeting was held on May 23, 2016 in Bīriņi, Vidriži rural territory. Later, three meetings of plan development steering group and individual meetings with owners of the adjacent lands were held. A meeting for discussing the plan among anyone interested took place on February 24, 2017. The plan was approved on June 22, 2017 by the Minister of Environmental Protection and Regional Development. The plan was developed for a 12-year period (2017–2029).

The development of nature protection plan was supervised by Gundega Freimane (Ābelīte). Experts of ten different fields were involved (experts on mires, forests, freshwater, botanists, ornithologist, experts of mammals and invertebrates, as well as hydrogeologist and experts on ecosystem service assessment). Field inventories were carried out in 2016 (Figure 171).

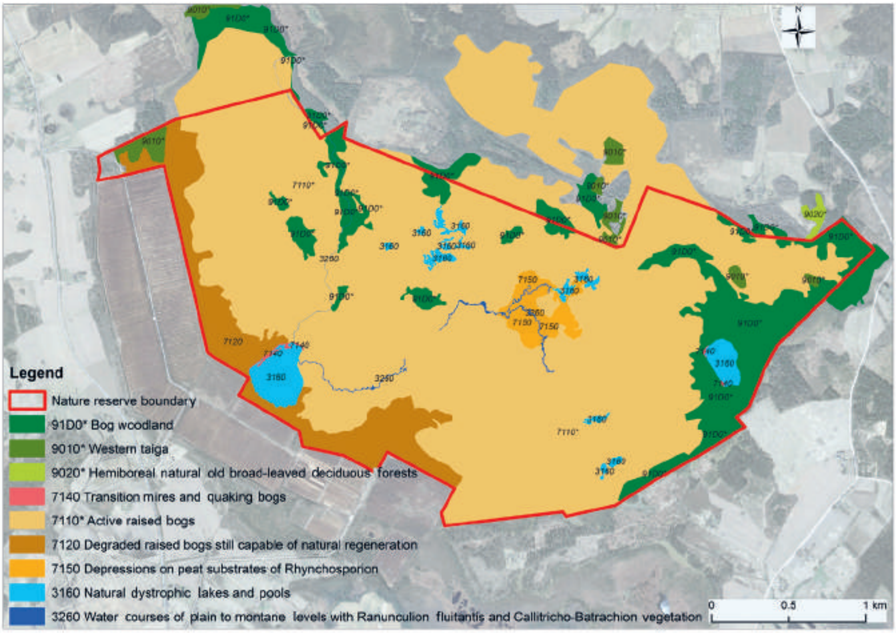

Figure 171. Distribution of protected habitat types (EU Habitats Directive, Annex I) in Lauga Mire. Map prepared by A. Rudusāne. Ortophotomap at scale 1:10,000, 2013–2015, © Latvian Geospatial Information Agency.

Protected habitats listed in the European Union's Habitat Directive cover 99.7% of the area of nature reserve. Four of them are protected mire habitats, two forest and two freshwater habitats. The protected mire habitats occupy 627 ha (84.7%) of the nature reserve; protected forest habitats – 86.3 ha (11.6%), freshwater habitats – 23.8 ha (3.2%). The largest proportion of the nature reserve is covered by active raised bog with two rather large bog lakes – Višezers Lake (10.5 ha) and Lode Lake (4.7 ha); there is also a large number of smaller dystrophic (brown-water) bog lakes (5.8 ha in total). There is a bog river that is particularly significant, it flows out in the eastern part of the mire, sometimes disappearing under the peat, flows into Višezers Lake and outflows from it northward. These habitats provide the necessary living environment for typical mire plants, as well as for birds, including rare, protected species.

In total, 35 species protected in Latvia[58] were found. Out of 22 protected bird species, 17 are included in Annex I of Birds Directive[59] and 21 are protected in Latvia, four bird species are so called micro-reserve species. Also 12 plant, invertebrate and mammal species included in Annexes of Habitats Directive have been recorded.

In the nature protection plan, the following long-term management objectives were set:

- ✔ to ensure the protection and conservation of Lauga Mire as a complex ecosystem by paying particular attention to restoring and preserving the water level of Višezers Lake that is essential for the entire mire. To prevent further degradation of the mire, the average water level in lake should be 58.3–58.5 m above the sea level;
- ✔ to provide favourable conditions for protected mire, forest and freshwater habitats; foster the restoration potential for degraded raised bog habitat;
- ✔ to provide a favourable conservation status for populations of protected and typical plant and animal, especially bird, species.

58 Included in Cabinet Regulation No 296 of 14 November 2000, On the List of Specially Protected Species and Specially Protected Species whose Use is Limited, or Cabinet Regulation No 940 of 18 December 2012, On the Procedures for the Establishment of Micro-reserves and Their Management, Conservation as well as Interpretation of Micro-reserves and Buffer Zone.

59 European Parliament and Council Directive 2009/147/EC of 30 November 2009 on the conservation of wild birds.

As justified in nature protection plan, a significant contribution to long-term objectives can be achieved by replacing the existing temporary dams on the ditches with stable, persistent dams. There were temporary dams on all three ditches outflowing from Višezers Lake, on the western and south-eastern shores, built in 2000 by the owner of a nearby large cranberry farm who maintained them during this period. However, the resources available were not sufficient, and the technologies used were inadequate for these dams to persist. Water was leaking through the dams, and they had to be repaired regularly due to washing out. In the nature protection plan construction was scheduled for several dams on the ditches on the border with peat extraction fields. Since no agreement with the owners of all adjacent areas was achieved, not all of the planned dams were built within LIFE REstore project, as planned. However, construction of three stable, durable dams was carried out in 2018 (Figure 172). This created conditions for recovery of protected habitat of EU importance *Natural dystrophic lakes and ponds* (3160) (10.01 ha), and restored the water level in Višezers Lake at 58.3–58.5 m above sea level. It also provided the conditions for recovery of the raised bog habitat in an area of 309 ha, in the catchment area of Višezers Lake.

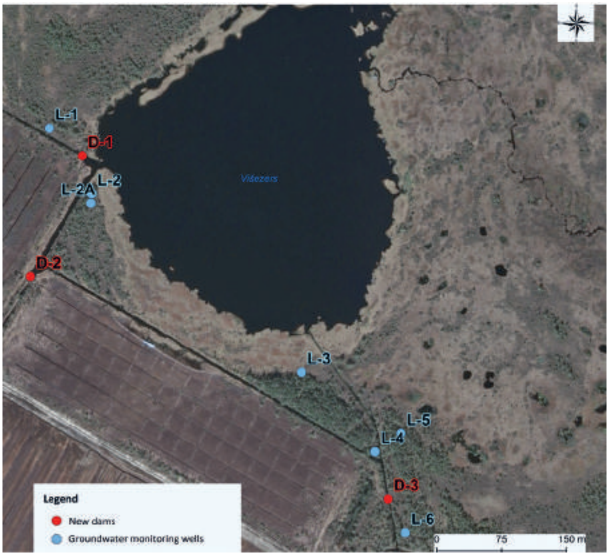

Figure 172. Locations of planned dams and piezometers installed within LIFE REstore project in Lauga Mire around Višezers Lake. Map prepared by A. Rudusāne. Ortophotomap at scale 1:10,000, 2013–2015, © Latvian Geospatial Information Agency.

Hydrological and hydrogeological modelling helped to assess the potential impact of blocking the ditches and to select the most appropriate solutions for restoring the mire ecosystem (locations of dams on ditches, types of dams) (see Chapter 4.3). Modelling results, together with field inventory data, were used for planning the management measures provided in the nature protection plan.

After evaluation of modelling results andfield inventories and after consulting with the inhabitants and landowners of the surrounding areas, it was decided that dams should be placed outside the nature reserve. If dams were built in the nature reserve (state-owned land, in legal possession of JSC "Latvijas valsts meži"), the water level would be kept at the current level only in the territory of nature reserve, but would drop downstream the dams, resulting in undesired water table in the land owned by the Gundegas farm. Therefore, it was decided to build the dams on the land belonging to Gundegas farm. This solution is also better from nature conservation point of view, as appropriate water table will be maintained in a larger area around the nature reserve. Both parties benefit from this cooperation: conservation of biodiversity within the nature reserve can be ensured, as well as optimal water table for further cultivation of large cranberries in the extracted peat fields adjacent to the nature reserve can be maintained.

Development of the nature protection plan and its approval significantly helped to facilitate the stakeholder involvement (landowners, responsible state and municipal authorities) and helped to agree on the proposed actions.

Restoration measures

After approval of the nature protection plan, construction design was developed in 2017, for building of three peat dams near Višezers Lake. It was planned that peat dams would retain the water in the mire, at the same time allowing runoff of excess water from Višezers Lake at high water level. The proposed water level set in the nature protection plan was 58.3–58.5 m above the sea level (Figure 173). Considering that the catchment of Višezers Lake is larger than 300 ha, and the lake surface area is ca. 10 ha, this was considered as the most appropriate solution.

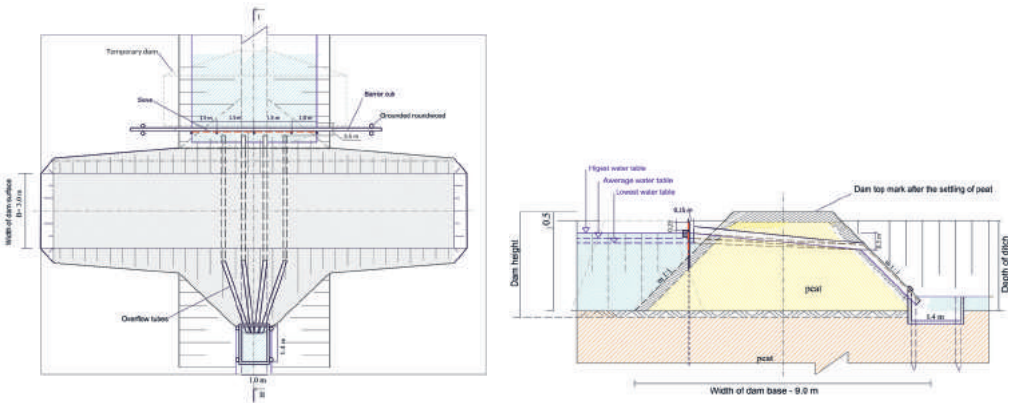

Figure 173. The construction of dams used for blocking of ditches in Lauga Mire. Drawings by J. Nusbaums.

The construction design was submitted to the Building Board of Limbaži municipality and approved on May 18, 2018. The Nature Conservation Agency announced the procurement of dam construction. In autumn of 2018, a contract was signed with SIA "E Būvvadība". Dams were constructed within one week in November 2018.

In places where dam construction was planned, trees and shrubs were removed. Sediments accumulated over many years were cleaned from ditch base. Since peat dams were built on a ~6 m thick layer of peat (measured during the development of construction design), ditches were cleaned to reach stable and well compacted peat. Material for the construction of peat dams was taken from sites downstream of the dam site. Mini excavators adapted for work in peatlands were used. The unladen weight of the units of the equipment was 3.5 tonnes. However, due to the extended track width, their pressure per square metre of ground was less than the pressure of the human foot.

During the construction work it was important to ensure that the dam would be tightly connected with the existing peat layer. This ensures that dams are firmly held in place. They hold the water pressure of Višezers Lake, and prevent water flow through the edges of dams. After construction, dams were covered with turfs with living vegetation obtained during the construction works (Figure 174). This way, the overgrowing of dams with vegetation is facilitated, as well as additional stability of dams is ensured. Soon after the construction, the dams became a part of mire landscape.

A B C

Figure 174. Construction of peat dams in Lauga Mire. Photos: G. Šusts.

Since the dams are made of peat, peat compaction and dam settling is continuing for some time after the completion of earthwork.

In order to avoid significant raise of water table in the territory of the adjacent cranberry farm, and to maintain the water level in Višezers Lake as planned in the nature protection plan, smooth-walled drainage pipelines DN200 were embedded in dams. As dams will continue to settle, also the pipelines will settle. Pipelines will no longer be at the initial height when the peat will be fully compacted. For this reason, pipeline ends are equipped with a bend at an angle of 67°, and they can be adjusted to a level specified in the nature protection plan to the nearest 0.01 metres.

Peat dams of this type have already proved to be efficient and durable in numerous peatland rewetting projects in Latvia and in many other countries (e.g. Nusbaums 2008; Vestarinen et al. 2014). If they are properly constructed, there is no need for repair and other additional investment in the coming years. This is considered to be an important advantage compared to, for example, wooden dams (Priede (ed.) 2017). In 2019, it is too early to evaluate their impact on mire restoration in Lauga Mire Nature Reserve. However, it is very likely that this is a successful long-term investment for the improvement of mire ecosystem.

Water table monitoring

For the assessment of rewetting success in Lauga Mire Nature Reserve, seven piezometers were established in a relatively undisturbed part of mire (Table 26). One of the seven piezometers (L2-A) was equipped with a filter interval on the sandy sediment layer under the peat, in order to control the vertical water exchange between soil horizons. The other piezometers were equipped with filter intervals in peat. Construction was similar for all piezometers (except L2-A) – a 2.5–3 m long 40 mm diameter PVC tube, of which a ~0.5–0.7 m section was left above the ground. Its lower part was equipped with 1 m long perforated filter. The tube was sealed from both the bottom and the top with 40 mm diameter PVC caps. The lower cap was glued but the upper cap was left to be removed for monitoring measurements. To prevent any movement of the tube, it was supported with a metal rod where the borehole does not reach the mineral ground (Figure 163 in Chapter 6.3.3).

Hydrological measurements were undertaken manually with Electric Contact Meter *Seba KLL Mini, 10m*. The equipment consists of a smooth measuring tape with a sensor at the end. By placing the measuring tape in tube and slowly lowering it, the sensor contacts the water, gives a sound signal, and the result can be read out. Measurements can also be made with a simple smooth measuring tape with a counterweight. The measuring tape is immersed in tube and the measurement can be recorded when the contact with water is heard. During the first measurement it is necessary to measure the length of the pipe above the ground. The groundwater table must be measured in all wells, and the length of each pipe above the ground must be subtracted from these measurements, resulting in a groundwater level below the ground.

The piezometers were installed on May 15, 2018, in accordance with the hydrological monitoring programme and the license for the use of subterranean depths issued by State Environmental Service. Since August 22, 2018, the habitat expert of Nature Conservation Agency manually measured water table in wells once a month.

In interpretation of the groundwater monitoring data, the precipitation data taken from the Latvian Environment, Geology and Meteorology Centre of the period from August 2018 to March 2019 were used. Data from the nearest meteorological station in Sigulda (ca. 17 km from Lauga Mire) were applied.

Table 26. Numbers and coordinates of piezometers, LKS-92 coordinate system.

No of piezometer	L-1	L-2	L-2A	L-3	L-4	L-5	L6
Coordinates X (E) Y (N)	540915 348195	540964 348119	540963 348108	541207 347912	541292 347820	541322 347841	541327 347726

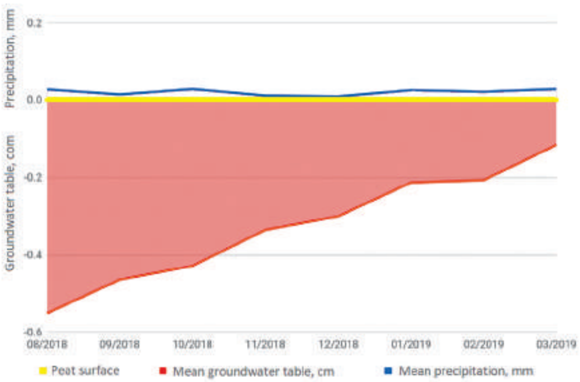

Figure 175. The first results of groundwater table monitoring in Lauga Mire.

The first results of groundwater table monitoring are presented in Figure 175. In August 2018, very low groundwater table was observed (from -31 to -124 cm); it was particularly low nearby the proposed dam locations. In autumn and winter, gradual rise of groundwater table was observed. In March 2019, it reached the peat surface in two wells. The lowest water table after building of dams was recorded in one of the wells located further away from the dams (-61 cm).

It is too early to make conclusions on the impact of dams, as the groundwater table is being monitored only for a few months after blocking the ditches. Monitoring during the first seven months shows gradual rise of water table, however, it might be related to predominantly natural condition (lower air temperatures than in summer and thus lower evapotranspiration). During the monitoring period no significant increase in precipitation was recorded. The actual impact of ditch blocking on groundwater table may be evaluated only a few years later using data of monitoring from several years. It is planned that groundwater table will be monitored by employees of the Nature Conservation Agency for at least 10 years after the end of the LIFE REstore project. Groundwater table data also should always be analysed in relation to the amount of precipitation.

Vegetation monitoring in Lauga Mire

Vegetation monitoring in Lauga Mire was commenced in August 2017. Ten permanent vegetation sample plots were established in the degraded part of the mire close to the ditches, where rise of groundwater table was expected after building of dams. Ten reference plots were established in the intact part of the mire. The size of each sample plot was 1 m^2 (1 x 1 m), and they were arranged in two transects. In each sample plot, all species of plants and lichens were identified and recorded, and the amount of their cover was estimated by eye. All sample plots were photographed.

In the sample plots in the degraded part of mire, 18 species of bryophytes and vascular plants were recorded. Among them, the most characteristic tree species were *Pinus sylvestris* and *Betula pendula*; the dwarf shrub species were represented by *Calluna vulgaris*, *Ledum palustre,* and *Empetrum nigrum*. Species characteristic to the herbaceous layer were *Rubus chamaemorus and Oxycoccus palustris*. The bryophyte cover was composed of *Dicranum polysetum*, *Pleurozium schreberi*; also a small cover of *Sphagnum fuscum*, *S. rubellum*, *S. angustifolium*, *S. magellanicum* was recorded.

In the intact part of Lauga Mire, species composition was similar to the one described above, but also species typical for undisturbed raised bogs were found, such as *Andromeda polifolia*, *Drosera rotundifolia*, *D. anglica*, *Eriophorum vaginatum*, *Utricularia minor*. Next time, the sample plots will be surveyed in vegetation season of 2019.

Impact of rewetting on greenhouse gas emissions

In order to evaluate the impact of mire restoration on greenhouse gas (GHG) emission changes, GHG emission measurements were carried out in Lauga Mire. More about GHG measurements in Chapter 3.

For planning of rewetting in Lauga Mire, default emission factors included in the 2013 Appendix to the 2006 IPCC Guidelines: Wetlands (Hiraishi et al. 2013) were used. According to the default GHG emission factors, the GHG emission reduction, mainly due to the reduction of CO_2 emissions, is 2900 t CO_2 eq year (9.4 t CO2 eq ha^{-1} year). Using emission factors obtained by LIFE REstore project, it was found that the actual GHG emissions do not decrease after blocking of ditches (rewetting). However, according to IPCC 2006 Guidelines, GHG emissions from natural ecosystems must not be accounted. For example, the guidelines explicitly state that the potential growth of GHG emissions in case of transforming forest to wetland, as well as carbon losses from deforestation should not be accounted. Therefore, in the project impact calculations for non-economic rewetting scenarios, including restoration of the drained part of Lauga Mire, it is assumed that GHG emission reduction is in line with GHG emissions, with the status quo. According to the results of the LIFE REstore project, GHG emissions from the rewetted part of Lauga Mire correspond to 2.7 thousands t CO_2 eq year (8.9 t CO_2 ha^{-1} year), which is considered to be a reduction of GHG emissions in a result of the project.

Change in ecosystem services after restoration

It is concluded in the evaluation of ecosystem services that rewetting in Lauga Mire Nature Reserve will result in a small positive change in regulation services provided by this area. Lauga Mire Nature Reserve provided highly valued regulation services already before the rewetting. The highest ranked regulation services in the territory are: dilution of pollution, erosion control, water storage capacity, soil ability to adsorb and accumulate nutrients. Provisioning services are available, but their values is rather low (wild berries, mushrooms, animals, fish that can be used for food). It is expected that regulatory services will be a priority value also after hydrological restoration in the area. More about the assessment of ecosystem services – see Chapter 5.

Conclusions

Nature protection plan is a suitable tool for planning management activities, as it allows comprehensive evaluation of various aspects, helps to discuss the necessary measures with stakeholders (landowners, state and municipal authorities, general public) in a timely and detailed manner, and it facilitates the approval of planned ecosystem restoration works. This was also confirmed by the rewetting in Lauga Mire.

Peat dams have proven to be a suitable and sustainable solution for the elimination of drainage influence in raised bogs. This is confirmed also by ditch blocking experience in Lauga Mire.

When constructing dams in Lauga Mire, a technically simple solution was found to ensure optimal water levels by peat dams with built-in pipes. At present, there is not enough experience in construction of this type of dams in Latvia, so it is too early to evaluate their long-term performance. So far, a similar solution has been applied in Ķemeri Mire in 2006 (Ķuze, Priede 2008). If dams of this type will prove their effectiveness in the long term, a similar design could be used in other drained peatlands.

Monitoring of groundwater and vegetation needs to be continued in order to assess the restoration success. It is likely that recovery of the water table and improvement of the condition of mire ecosystem will be observed only within several years.

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6.4. Optimization model for sustainable management of areas affected by peat extraction

Līga Brūniņa, Elīna Konstantinova, Aija Peršēvica, Juris Pētersons, Aldis Kasakovskis

Summary

Based on the results obtained in LIFE REstore project, an optimization model for sustainable management of areas affected by peat extraction has been developed. It serves as a decision support tool for planning the future use of these areas. The developed model reflects the benefits in sectors of climate change mitigation, socio-economic and environmental benefits which would be provided by the implementation of selected after-use scenario of extracted peatlands. The potential users of the model are entrepreneurs, peat producers, owners and managers of territories, as well as state and local government authorities.

The model proposes an estimation of a "value" for each after-use scenario based on (1) environmental benefits (economic value of ecosystem services); (2) estimation of the expected climate mitigation – reduction of greenhouse gas emissions; (3) assessment of the financial benefits by calculating the return on investments that can be obtained by merchants, site managers or landowners.

In Latvia, in accordance with legislative acts and using the accumulated experience, several types of reclamation in areas affected by peat extraction can be implemented. Their objectives can be both economic activity and biodiversity conservation. Each of the after-use scenarios can provide benefits of various types. Considering the future management of territories, it is essential for landowners to take sustainable decisions which ensure a balance between environmental, social and economic interests.

Using the results of the LIFE REstore (economic assessment of ecosystem services, measurements of

greenhouse gas emissions, results of peatland inventory, descriptions of after-use scenarios) and the developed optimization model, reasonable management decisions can be made regarding the future use of the areas affected by peat extraction; to estimate the potential costs of reclamation measures; to plan the expected financial return, to estimate the contribution to climate change mitigation, and, by evaluation of ecosystem services, also to respect nature in decision making.

Introduction

In 2017, 0.998 million tonnes of peat were harvested in Latvia. Of them, 95% was exported, mainly to meet the needs of the horticultural sector. In 2017, peat exports also accounted for 1.3% of total volume of Latvian export. The peat substrate produced in Latvia reaches over 100 countries, including China, Japan and Australia (VARAM 2017). On the one hand, the obtained peat resources provide significant economic benefits (Tcvetkov 2017). However, peat extraction has an impact on the hydrological conditions and vegetation of natural ecosystems, resulting in peatlands which are no longer able to provide ecosystem services typical for undisturbed mires (Kimmel, Mander 2011). Such peatlands also loose their climate regulation capacity and other important functions. Extracted peatlands become an important source of greenhouse gas (hereinafter – GHG) emissions, therefore their sustainable management is essential for reducing GHG emissions in the long term (Dunn, Freeman 2011). Sustainable management of extracted peatlands should focus on synergy between environmental and climate measures, integrating climate, environmental and biodiversity objectives into responsible and sustainable management and further use of areas affected by peat extraction (Renou-Wilson et al. 2011).

In the LIFE REstore project, areas affected by peat extraction were inventoried for their assessment and for the identification of their potential after-use scenarios. Areas affected by peat extraction were identified (Chapter 4.5), revegetation in cutaway peatlands was studied (Chapter 4.4), reclamation measures which are the most suitable for Latvian conditions were analyzed (see Chapters 6.2, 6.3), GHG emission were measured (Chapter 3) and ecosystem services were assessed (Chapter 5). The optimization model for sustainable management of areas affected by peat extraction (hereinafter – optimization model) summarizes these results in a single and practically usable tool that allows us to evaluate the different after-use scenarios in interconnections.

As concluded by LIFE REstore project after an inventory of areas affected by peat extraction, according to the situation on January 1, 2016, reclamation has not carried out in about 18 thousand hectares of cutaway peatlands. These areas are degraded and, consequently, functions of peat formation and natural mire ecosystem are disturbed or destroyed in most of these areas. Within this model, the most appropriate after-use scenarios of these areas were evaluated and recommended. It is important to note that the situation in peat extraction areas is constantly changing (peat extraction is completed in some territories, while the use of newly licensed areas is started). However, the model and its application possibilities are intended to provide reasoned, scientifically validated and accurate information on various peatlands (both by area size and geological conditions) affected by peat extraction – after-use scenarios, their impact and expected results.

The optimization model includes detailed financial calculations and return on investment as well as economic calculations. In addition to the financial return, data on GHG emission reductions and changes in ecosystem services resulting from one or another after-use scenario were also taken into account in the calculation of economic values. The optimization model also allows determining the necessary share of public funding or the deficit rate that is important in cutaway peatlands which are abandoned long time ago. Consequently, the model provides a possibility to determine the necessary public funding (accounting of financing deficit) for after-use scenarios which give a positive economic return (reduction of GHG emissions (calculated as CO_2 equivalent), increase of value of ecosystem services), but the implementation of which is not economically profitable for merchants.

According to the legislative acts, several after-use scenarios can be implemented after the completion of peat extraction: afforestation, establishment of croplands, perennial grasslands or berry plantations; rehabilitation; creation of water bodies (Chapter 6.2). During the project, several reclamation types were tested in project demo sites: plantations of highbush blueberries and large cranberries; afforestation; reintroduction of Sphagnum mosses. For other after-use scenarios and for conditions which are necessary for their implementation, expert opinions and results of scientific studies were compiled.

After-use scenarios of extracted peatlands can be divided into two groups: (1) the purpose of after-use is to carry out economic activity and (2) to restore natural peatland ecosystem functions or to convert the area into another near-natural area. The first group includes (a) cultivation of berries (large cranberries, highbush blueberries), (b) planting of fast-growing tree species for energy production, (c) establishment of cropland, (d) establishment of perennial grasslands, (e) paludicultures. The second group includes (a) rehabilitation, (b) afforestation (3) creation of water bodies.

Each of the above mentioned after-use scenarios of peat extraction sites provide benefits of various types – economic profits, diverse ecosystem services or GHG emission reduction. It is important to emphasize that the implementation of each after-use scenario has different preconditions (such as geological structure, hydrological conditions, properties of residual peat). Site characteristics determine both which after-use scenarios can be implemented and what is the necessary investment for the implementation of respective after-use scenario. The optimization model includes the requirements for each after-use scenario. Therefore, before the calculations and selection of the most appropriate after-use scenario, the optimization model allows evaluating which of the after-use scenarios can be implemented in the particular territory.

Material and methods

The optimization model includes a very detailed financial calculation algorithm that provides a linear correlation between the area to be reclaimed and the financial and economic parameters of reclamation measures in this territory.

The results can be interpreted in two ways: return of private investment (financial) (based on investment and return on investment), and valuation (economic) of national common good (based on environmental and climate benefits). Such option shows an investment return in the context of the availability and sustainability of resources.

First of all, in order to assess the **income or financial return** provided by the site after its reclamation, the investments necessary for the implementation and maintenance of a particular after-use scenario are taken into account, as well as the expected revenue. For the comparison of revenue provided by various after-use scenarios, the following financial parameters are calculated.

- ✔ The *repayment period of investments* is the period (years) in which the investment used for implementation of a particular after-use scenario is paid off. If the result shows "does not pay off", the investments necessary for an implementation of the particular after-use scenario are higher than the potential income (cumulative cash flow is negative).
- ✔ The *net present value of the investment* shows whether the future revenue of after-use scenario (discounted or present value) is higher or lower than the total cost (investment, renewal, maintenance and production costs) of today's (discounted) value. If the financial net present value of the investment is greater than zero, this indicates that the particular after-use scenario is cost-effective. If the value of indicator is zero, the present (discounted) value of the project revenue is equal to the cost of implementing the certain reclamation type. If the value of indicator is less than zero, the particular after-use scenario is not profitable, and the planned revenue from the site is less than the necessary investment.

- ✔ The *financial internal rate of return* shows the possibility of income from after-use scenario to cover the investment and operating costs by calculating the rate of return on investment (in percentage terms). If the value of this indicator is greater than the discount rate used in calculations, the after-use scenario is profitable. If the financial internal rate of return is equal to the discount rate used in the calculations, the revenue from the planned after-use is sufficient to cover the investment and operating costs. If the value of the index is less than the discount rate used in the calculations, the chosen after-use scenario is unprofitable.
- ✔ The *funding deficit rate* is a part (%) of investment costs not covered by net revenue generated by the particular after-use scenario (operating income minus restoration, maintenance and production costs).

Secondly, the **impact** of after-use scenario **on changes in GHG emissions** is calculated taking into account the results GHG emission measurements obtained by LIFE REstore project (Chapter 3). GHG emissions are increased or decreased by implementation of every particular after-use scenario. Additionally captured or emitted amount of GHG is recalculated in CO_2 equivalents tonne per year per hectare. In order to incorporate GHG emissions into the optimization model and into the overall comparison of after-use scenarios, the price of one CO_2 equivalent per tonne of gas is determined. The cost of CO_2 assumed in the optimization model is 20 EUR per tonne, according to impact assessment of LULUCF Regulation.

Thirdly, the environmental benefits of after-use scenarios are assessed using an **ecosystem services approach**, evaluating the provisioning, regulation and cultural services provided by sites. Each of these service categories is measured by considering several potential benefits. The economic evaluation of ecosystem services (Chapter 5.2) has been carried out in order to compare the benefits and to include them in the optimization model, obtaining the monetary value of each after-use scenario (EUR/ha).

The optimization model provides calculation of total monetary benefits (EUR) of all three aspects (financial return, climate change mitigation, ecosystem services) following the implementation of particular after-use scenario. In order to estimate the total benefits, the following calculations of economic return indicators are included in the calculation of optimization model.

- ✔ The *economic net present value of investment* shows whether the total benefits (financial, GHG emission changes and ecosystem services) of after-use scenario in their present value (discounted values) are higher or lower than the total investment (financial investment, renewal, maintenance and production costs) of their present value (discounted).
- ✔ The *economic internal rate of return* describes the economic benefits of after-use to society by calculating the rate of economic return of after-use scenario in percentage terms.

When evaluating the financial and economic returns of various after-use scenarios, it is important to realize that the result varies over time. Each after-use scenario has a different cycle in which it starts to pay off and develops its profitability. The model includes five life cycles (5, 10, 25, 50 and 100 years), which in turn are linked to the different payback periods of different after-use scenarios, their natural economic sustainability, and investment crediting conditions (the profitability of projects is calculated over a 10-year cycle).

The optimization model includes the gross margins[60] calculations[61] (prices of 2017) compiled by the Latvian Rural Advisory and Training Centre. Such approach to calculating investment cost estimates is used in cases when it is necessary to assess the overall situation in a particular region or a country as a whole and it helps spatial planners or law-makers to rely on uniform approach. However, given that every area affected by peat extraction is different, also the amount of necessary investment for every after-use

60 Gross margin is the difference obtained by subtracting variable costs from the gross production estimate.

61 Agricultural gross margin estimates for 2017. Latvian Rural Advisory and Training Centre, http://new.llkc.lv/lv/nozares/ekonomika/bruto-segumi.

scenario is different. In the optimization model, the territory can be evaluated using several characteristics, which are important to distinguish the amount of necessary investments. User can also enter his own costs for the implementation of after-use scenario.

The optimization model is available in *.xls* file format, as well as in an easy-to-use, interactive online tool. When entering the basic parameters of the site (such as the type of peat upper layer, peat decomposition degree, average groundwater table, etc.), it gives a general overview of after-use scenarios which can be implemented in a particular peat extraction site, and their comparison. The tool (available at: https://karte.ozols.gov.lv/optimizacijas.modelis/) is linked to the database of peatlands affected by peat extraction, which allows the selection of areas suitable for various after-use scenarios in Latvia.

When evaluating the results described below, it is important to take into account that due to the lack of precise data, the information below is illustrative and provides a general insight into the possible types of after-use of 18 thousand hectares of areas affected by peat extraction identified in the LIFE REstore inventory (Chapter 4.5).

Results and discussion

The optimization model developed during the LIFE REstore project allows to draw several conclusions regarding the after-use of areas affected by peat extraction. When using the developed optimization model and modelling possible after-use scenarios in areas affected by peat extraction in Latvia, on the basis of geological and hydrological conditions of the territories, it was concluded that rehabilitation is the one after-use scenario which can be implemented in most of the cases (Figure 176). Results can be explained by the fact that the implementation of rehabilitation (rewetting) has the least restrictive criteria. There are only two restrictive criteria for this after-use scenario – residual peat layer should be at least 0.3 m thick and the area cannot be flooded for more than 90 days a year. About 96% of 18 thousand hectares of areas affected by peat extraction could be rewetted, as ascertained by model calculations.

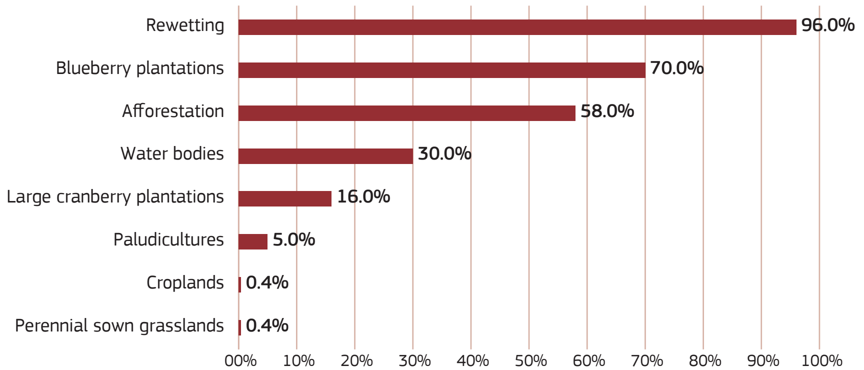

Figure 176. After-use scenarios suitable for extracted peatlands in Latvia, based on geological and hydrological conditions (results of model calculation).

At the same time, the data obtained by optimization model confirm that peat extraction sites are less suitable for establishment of cropland and perennial sown grasslands. The implementation of these two after-use scenarios is only possible in 0.4% of all extracted peatland areas.

It is important to note that, although the cultivation of blueberries and large cranberries can be qualified as a single after-use scenario, the opportunities of growing each of these crops in the former peat extraction sites are very different. The results of the model (Figure 176) show that highbush blueberry cultivation is possible in 70% of extracted peatlands, but large cranberry cultivation – only in 16% of the 18 thousand hectares of unreclaimed extracted peatlands. About 58% of these areas in Latvia could be afforested.

Socio-economic benefits

Investment is necessary for the implementation of each after-use scenario – either rewetting or implementation of an economic activity is planned. The amount of investment for each after-use scenario is different. The average investment necessary for implementation of every after-use scenario is shown in Figure 177.

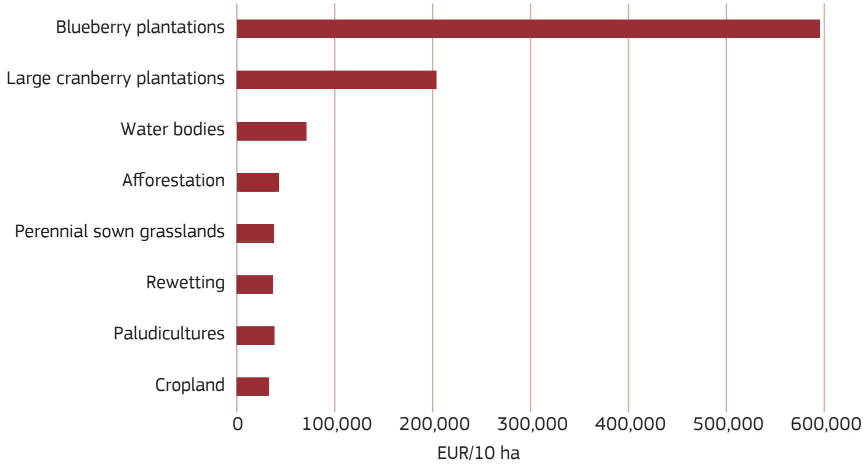

Figure 177. Average after-use costs per 10 ha.

The potential financial return is shown in Figure 178. It is modeled for 10 ha large areas, for a 10-year period. Growing of highbush blueberries is the after-use scenario with the highest financial return; despite the relatively high costs, the investments pay off in the seventh year. Also the establishment of large cranberry plantation gives a similar result. It is logical that such a high financial return is not expected from rewetting and creation of water bodies, as these after-use scenarios do not yield profits in the next 10 or even 50 years. One of the long-term socio-economic benefits of the reclamation of cutaway peatlands is the formation of peat. However, as such calculations would be based on many hypothetical assumptions, no calculation of such revenues is included within the optimization model.

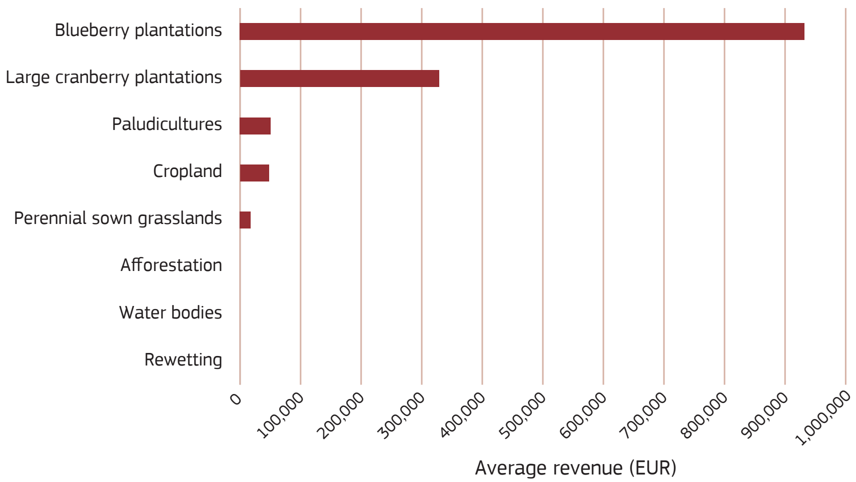

Figure 178. Average revenue (EUR) from various after-use scenarios, calculated for 10 ha large area, for a 10-year period.

Afforestation of cutaway peatlands is not financially profitable in the first 10 years. It can be explained by the use of a tree species (birch), which does not provide a significant volume of timber within 10 years. It is important to highlight that the potential for afforestation depends on species of trees planted. If the purpose of afforestation is economic activity to gain a profit in a short time, it is recommended to plant fast-growing tree species (willow, poplar, aspen).

Benefits from greenhouse gas emission reduction

Reclamation of cutawayh peatlands is necessary not only for economic benefits; it provides also social benefits. Social benefits resulting from reclamation of extracted peatlands are reduction of GHG emissions and biodiversity restoration. GHG emission reduction provided by various after-use scenarios is shown in CO_2 equivalents in Figure 179.

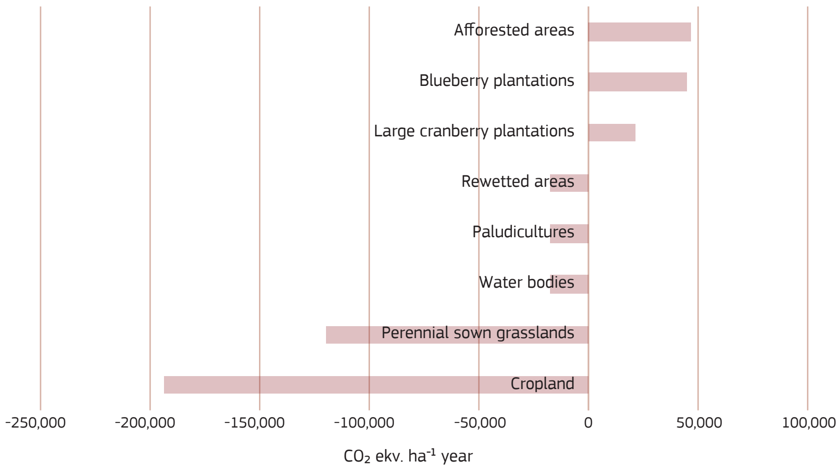

Figure 179. GHG emission reduction potential (CO_2 equivalents) of various after-use scenarios (10 hectares, 10-year period).

The greatest benefits of reducing GHG emissions are provided by such after-use scenarios as afforestation, highbush blueberry and large cranberry plantations. Afforestation, especially pine plantations, can reduce GHG emissions in extracted peatlands in the long term. From the point of view of climate change mitigation, afforestation can be considered as the most efficient management type of cutaway peatlands.

The two most inefficient after-use scenarios are the establishment of perennial grasslands and croplands. In 10-year period, they not only do not ensure GHG reduction, but they are significant sources of GHG emissions. Also the creation of water bodies, paludicultures and rewetting do not ensure the reduction of GHG emissions (see Chapter 3).

Environmental benefits

Monetary values of ecosystem services of various after-use scenarios (calculated in 10 ha large areas for a 10-year period) are shown in Figure 180.

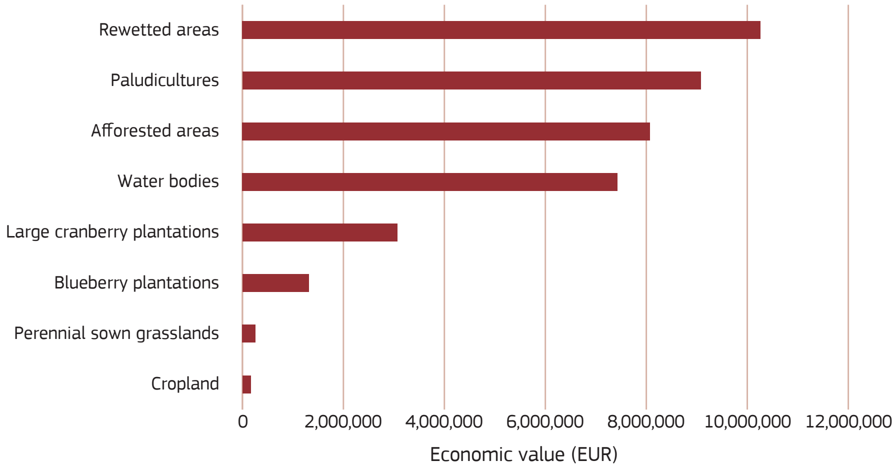

Figure 180. Economic value of various ecosystem services of various after-use scenarios; for 10 ha over a 10-year period.

After-use scenarios which ensure significantly higher values of ecosystem services are: afforestation, rewetting, and paludicultures. It can be concluded that natural areas can provide significantly higher values of ecosystem services, whereas after-use scenarios which are primarily devoted to economic activity provide ecosystem services with significantly lower value.

When analyzing after-use scenarios which are related to economic activity it can be concluded that growing of large cranberries provide more valuable ecosystem services than other land use types after the peat extraction (more on assessment of ecosystem services: see Chapter 5).

Conclusions

Evaluating the after-use scenarios from the perspective of socio-economic benefits, it can be concluded that, although the largest investments are necessary for the establishment of highbush blueberry plantations, also the financial return from this after-use scenario is the highest in 10 years.

When evaluating after-use scenarios from a climate change mitigation perspective, the greatest benefit in 10 years is expected from afforested areas (regardless of whether trees were planted for restoration of near-natural environment or for energy wood production). Forest areas also have the highest economic value. Also the economic values of ecosystem services are the highest for afforested areas. When comparing after-use scenarios from ecosystem service point of view, it was concluded that the greatest value is for restored near-natural areas.

The largest economic contribution is provided by afforestation and cultivation of highbush blueberries. However, it is essential to develop a common vision in the decision-making process for the management of cutaway peatlands. Both demands and capacities of peat producers and landowners concerning the management must be taken into account, and also the principles of environmental sustainability and climate aspects must be respected. The most suitable after-use scenario according to national strategy, geological and hydrological conditions, regional employment and other factors should be selected already during the planning of peat extraction and during environmental impact assessment.

In Latvia, decisions on the after-use of areas affected by peat extraction must be responsible, sustainable and based on a balanced national economic development and the nature conservation aspects – providing the implementation of after-use scenarios related to both economic activity and restoration of biodiversity. This would ensure both economic growth and sustainability of natural resources and ecosystem services.

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