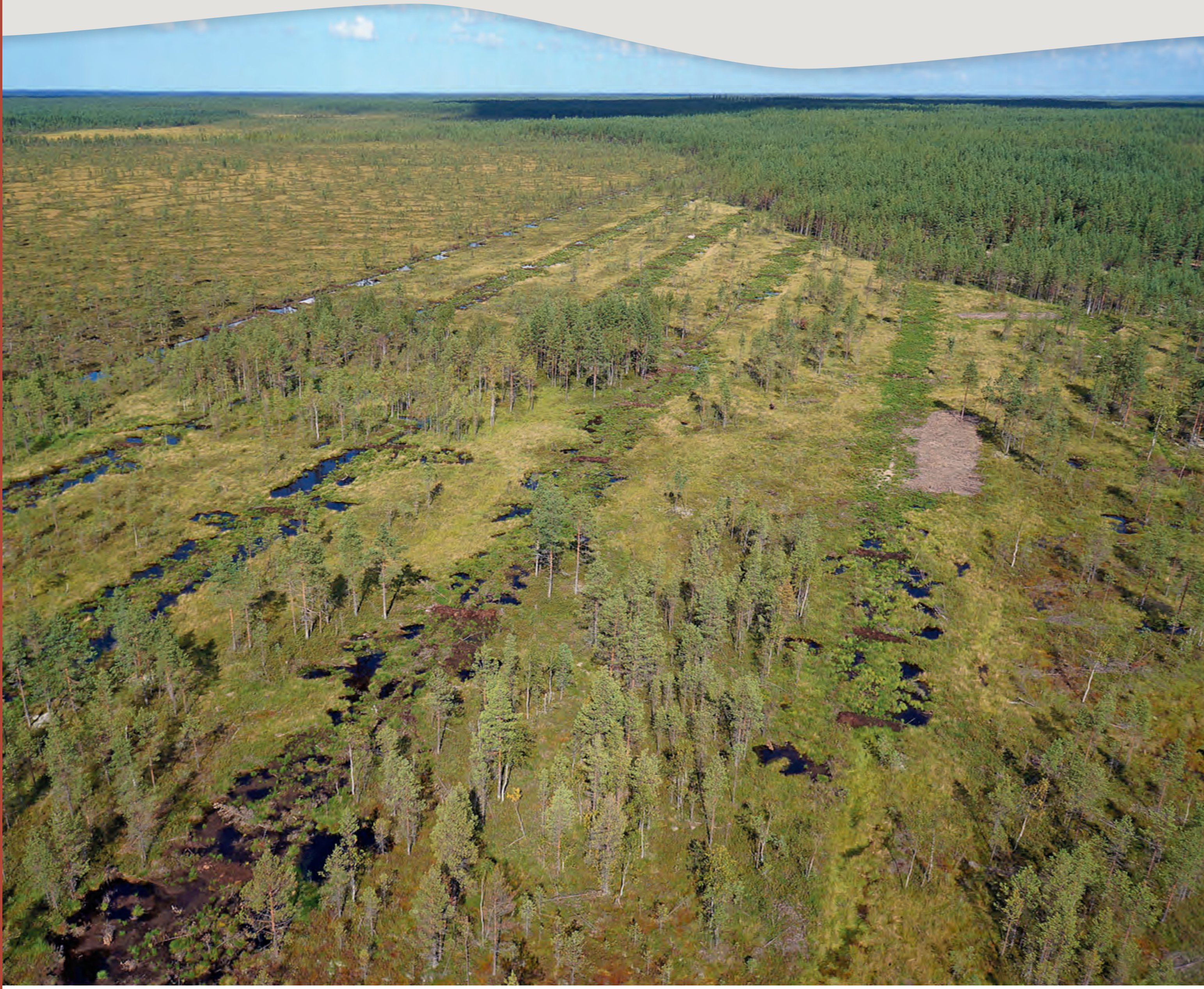
ECOLOGICAL RESTORATION IN DRAINED PEATLANDS – BEST PRACTICES FROM FINLAND

METSÄHALLITUS SYKE

Ecological restoration in drained peatlands

– best practices from Finland

Maarit Similä, Kaisu Aapala and Jouni Penttinen (eds)



Metsähallitus – Natural Heritage Services | Finnish Environment Institute SYKE

Maarit Similä
Metsähallitus Natural Heritage Services
maarit.simila@metsa.fi

Kaisu Aapala
Finnish Environment Institute
kaisu.aapala@ymparisto.fi

Jouni Penttinen
Metsähallitus Natural Heritage Services
jouni.penttinen@metsa.fi

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Layout: Marianne Katainen

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Eight years after restoration. PHOTO: MAARIT SIMILÄ

More than 25 years of experience

A new comprehensive handbook for the restoration of drained peatlands was published in Finnish in July 2013 (Aapala et al. 2013). The handbook was produced with the help of dozens of Finnish peatland experts. It compiles the knowhow accumulated over more than 25 years of peatland habitat restoration in Finland, together with useful background ecological information on peat and the hydrology of peatlands.

The handbook was primarily written on the basis of experiences gained from restoring peatland sites in protected areas. Our aim is to increase awareness of the ecological bases for peatland habitat restoration, and thereby promote effective peatland restoration work both inside protected areas and in areas where commercially forestry is practised. The handbook is intended for everyone involved in the planning and implementation of active restoration measures in peatlands that have been drained to promote forestry.

The production of the handbook was coordinated by the Finnish Expert Group for Peatland Restoration (SuoELO*) in connection with the Boreal Peatland LIFE project and the Forest Biodiversity Programme METSO, with funding from the Ministry of the Environment.

This abridged English-language version of the guidebook summarises the most important contents of the full Finnish version. The publication of the English version was financed through the Boreal Peatland LIFE project. We would like to warmly thank everyone who has contributed to the original handbook and this English summary version.

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Maarit Similä[1], Kaisu Aapala[2] and Jouni Penttinen[1]
Editors
[1] Metsähallitus Natural Heritage Services
[2] Finnish Environment Institute

*SuoELO is a collaborative working group consisting of experts from several key organisations including Metsähallitus, the Finnish Environment Institute, the Finnish Forest Research Institute, the Forestry Development Centre Tapio, the University of Eastern Finland, the University of Jyväskylä and the Ministry of the Environment. The Finnish Forest Centre joined the working group in 2013.

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Figure 1. Kurjenrahka National Park contains the most extensive protected peatlands in Southwest Finland. PHOTO: LENTOKUVA VALLAS.

1 Introduction

Kaisu Aapala and Maarit Similä

In international nature conservation policy contexts the restoration of ecosystems has become an important tool for mitigating biodiversity loss and safeguarding ecosystem services. The European Union's new biodiversity strategy (European Union 2010) and the 10th Conference of Parties to the international Convention on Biological Diversity held in Nagoya in 2010 both highlighted ecological restoration as a key means to halt biodiversity loss and the degradation of ecosystem services by 2020. Finland's own national nature conservation policies also aim to promote active restoration work in protected areas and in commercially managed forests (Valtioneuvosto 2012a, b).

Ecological restoration involves measures designed to help ecosystems that have been impoverished, damaged or destroyed due to human activity to revert to their natural state, or as near to their natural state as possible (Society for Ecological Restoration International Science & Policy Working Group 2004). Natural conditions and ecological processes can be re-established in peatland ecosystems affected by human activity much more rapidly with the help of well-planned restoration measures than by leaving them to return to a near natural state through slow natural processes.

One of the primary objectives of restoration is to improve the quality of species' habitats and biotopes, and thus slow or halt the rate of biodiversity loss.

The advantages of preserving and restoring peatlands with regard to mitigating climate change are also recognised in international climate policy-making. At the Durban climate conference in 2011 it was agreed that parties to the Kyoto Protocol could from 2013 onwards include the benefits of the restoration of wetlands, including peatlands, in their greenhouse gas reporting (COP 17 Durban 2011, Decision 2/CMP7).

Finland originally had natural peatlands with a total area of some 10.4 million hectares (Vasander 1998). Today the country has about 8.7 million ha of peatlands, of which some 4.7 million ha

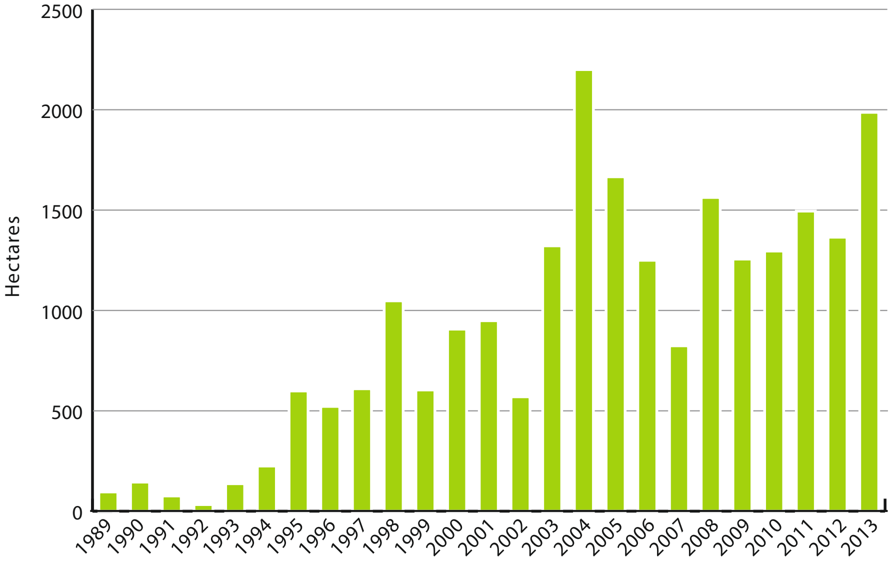
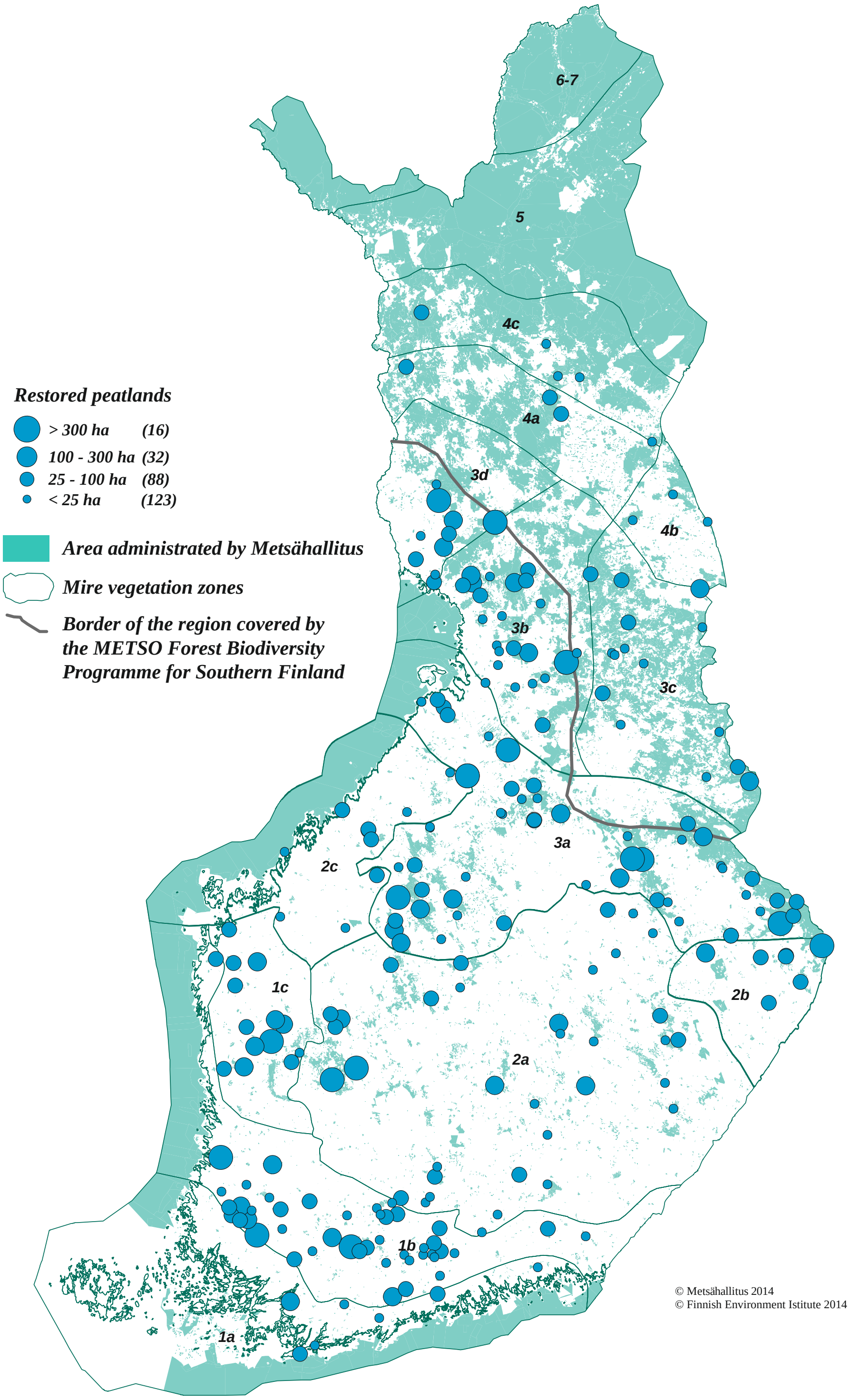


Figure 2. Areas of peatland restored annually in state-owned protected areas 1989–2013.

have been artificially drained and about 4 million ha remain undrained (Finnish Forest Research Institute 2013). Some 1.2 million ha of peatland lie within protected areas (Figures 1 and 4), though more than 50,000 ha of this area had been drained before the areas were protected (National peatland strategy working group 2011). During the years 1989–2013 peatlands with a total area of about 20,000 ha were restored (Figures 2 and 3). It has been estimated that ecological peatland restoration would still be needed in a total area of around 17,000 ha in existing state-owned protected areas and in some 1,000 ha in privately owned protected areas (Metsähallitus 2012).

The first peatland restoration trials in Finland were conducted in the 1970s and 1980s in peatland sites of very high ecological value very soon after they had been drained. Initially drainage ditches were blocked manually, but since 1992 peatland restoration work has usually involved machinery. The areas of peatland restored annually increased from the mid-1990s thanks to the availability of EU Life funding (Info box 2). Ecological habitat restoration measures became a more established means of managing protected areas from 2003 when the first national Forest Biodiversity Programme METSO was launched and a habitat restoration working group appointed by the Ministry of the Environment published its findings (Rassi et al. 2003).



← ***Figure 3.*** *Peatlands in protected areas where restoration work had been conducted by the end of 2013. The areas shown as administered by Metsähallitus include both lands and waters. Mire vegetation zones: 1a Plateau bogs, 1b–1c Concentric bogs, 2a–2c Eccentric bogs and Sphagnum fuscum bogs, 3a–3d Sedge aapa mires, 4a–4c Flark aapa mires, 5 Northern aapa mires, 6–7 Palsa mires and orohemiarctic mires.*

INFO BOX 1

METSÄHALLITUS NATURAL HERITAGE SERVICES MANAGES FINLAND'S PROTECTED AREAS

The Finnish State owns about 125,000 square kilometres of land – amounting to about one third of Finland's total land area (Figure 4, page 5). State-owned lands and waters in Finland are administered by Metsähallitus. Metsähallitus's Forestry Business Unit administers commercially managed forests, while Metsähallitus Natural Heritage Services is responsible for the ecological management of protected areas. Natural Heritage Services manages areas totalling 70,000 sq km (39,000 sq km of land and 31,000 sq km of marine and inland waters). In addition to these state-owned protected areas, Metsähallitus Natural Heritage Services also carries out habitat restoration and ecological management work in many privately owned protected areas around Finland.

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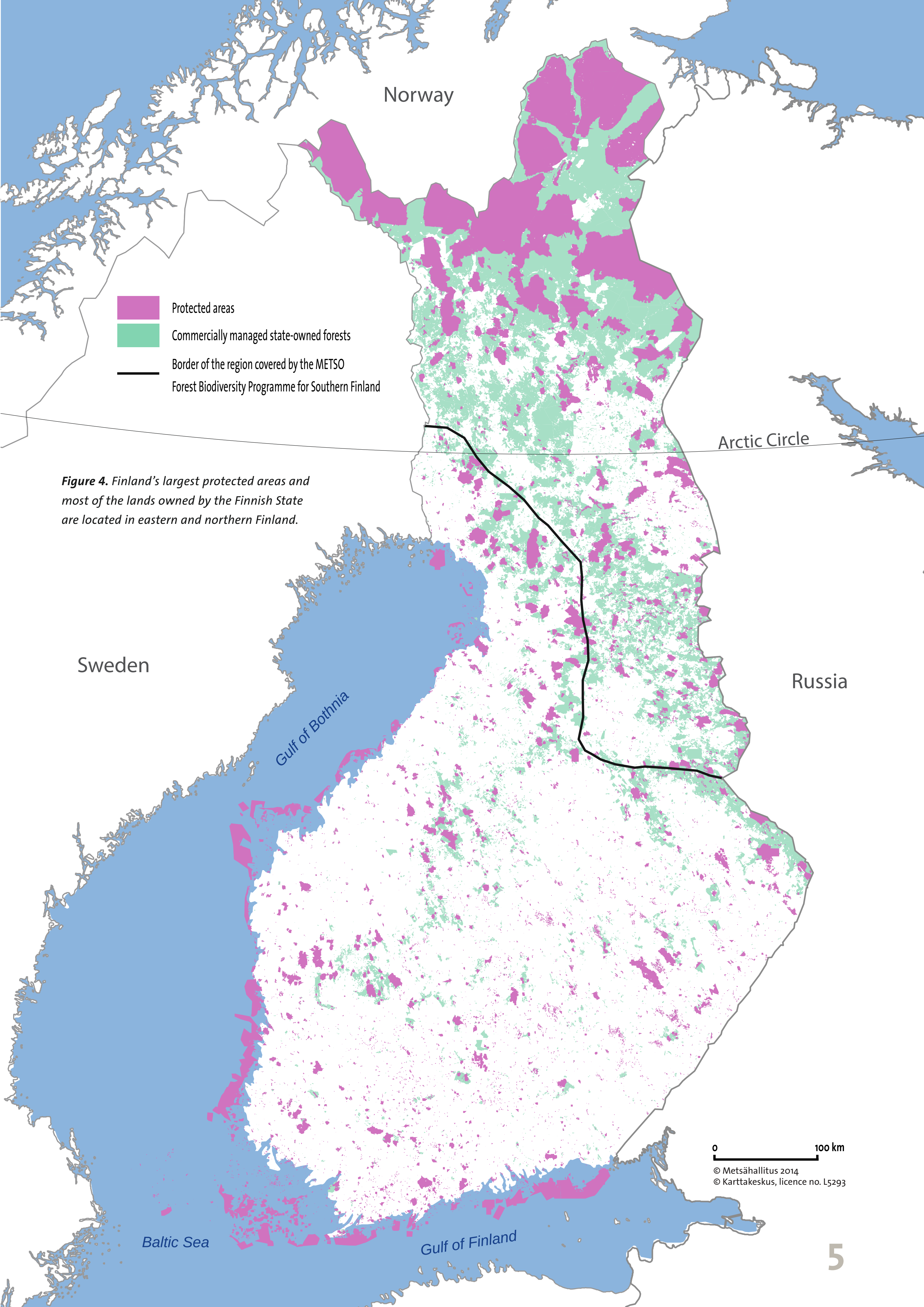


Figure 4. *Finland's largest protected areas and most of the lands owned by the Finnish State are located in eastern and northern Finland.*

EU Life projects and peatland restoration

Mikko Tiira

Peatlands and wetlands in LIFE projects

Many Natura 2000 habitat types are associated with peatlands. Those found in Finland include active raised bogs, aapa mires, bog woodlands, palsa mires and petrifying springs with tufa formation (Cratoneurion). Peatland habitats are the focus of many Life projects in Finland and elsewhere in the EU. By 2012 the European Commission had funded a total of 150 projects related to peatlands across Europe. These projects have promoted the conservation of peatlands through additional protection or enhanced land use planning, by restoring peatlands earlier cleared for agriculture or drained for forestry purposes, and even by recreating areas of peatland habitat where such areas had been lost.

Life projects related to peatlands in Finland

Finland's first Life projects were launched in 1995. By 2012 a total of 124 projects had been concluded or were under way, including about 50 Life Nature projects. Almost half of Finland's Life nature projects have concerned peatlands to a greater or lesser degree. The total budget for projects related to peatland restoration, including still ongoing projects, amounts to more than 40 million euros, about half of which has come from EU funds. By the end of 2012 areas of peatland habitat totalling more than 9,000 hectares had been restored around Finland using Life funding.

Life funding has particularly been used to restore aapa mires, for a total area of more than 4,000 ha. Some 1,700 ha of active and degraded raised bogs have also been restored, as well as just over 2,000 ha of bog woodlands, about 350 ha of alkaline fens, just over 100 ha of transition mires and quaking bogs (in projects focusing on sites valuable for their birdlife). A small number of sites with Fennoscandian springs and spring fens have also been restored.

Life projects related to peatlands elsewhere in the EU

In other northerly countries in the EU Life projects focusing on peatlands have been most numerous in Latvia (about 10). In Sweden there have been 13 projects, but these almost all focused on acquiring peatlands for protection. The project 'Life to ad(d) mire', launched in 2012, is the first Life project in Sweden to focus on peatland restoration.

The types of peatlands targeted by projects around the EU vary greatly. According to the Life projects databank, more than 80 peatland projects have been related to alkaline fens, particularly in Germany and Italy, but also in Belgium, Holland, the Nordic Countries, the Baltic Countries and Britain. Bog woodlands have been protected or restored through almost 80 projects, most widely in Finland and Germany, though Sweden and Latvia also have almost ten projects each targeting bog woodlands. The conservation of transition mires and quaking bogs has been promoted through almost 80 projects, with almost 15 in each of Finland, Germany and Belgium, and elsewhere 10 or fewer. Projects targeting raised bogs are by far the most numerous (over 100). In the British Isles many projects have striven to restore blanket bogs. Projects targeting aapa mires have mainly been realised in Finland, and to a lesser extent Sweden.

All Life projects also involve active publicity work. For example, in Finland's Boreal Peatland Life Project, information about the ecology, protection and restoration of peatlands has been publicised by various means such as a portable mire exhibition with comic strips and nature quizzes run on a computer, a series of 10 video programmes and guided trips to peatlands for children and people with disabilities. PHOTO: METSÄHALLITUS / JOHANNA ROTKO

→ *The oak spider (Aculepeira ceropegia), classified as vulnerable, is primarily found in peatlands in Finland, though elsewhere in Europe it is associated with other open and sunlit habitats.* PHOTO: NICLAS FRITZÉN.

2 Peatland restoration – needs and goals

Kaisu Aapala, Sakari Rehell, Maarit Similä and Tuomas Haapalehto

2.1 Why restore peatlands?

The diversity or Finland's natural peatlands and their flora and fauna has declined due to the actions realised to promote their commercial utilisation, such as the digging of drainage ditches to promote forest growth (Sections 3.4, 4.3 and 5.3), the clearance of farmland, and peat extraction. Even undrained peatlands are widely no longer in their natural state due to actions such as logging, site preparation for forestry purposes, the clearance of streams, the construction of reservoirs, and the extraction of groundwater (Kaakinen et al. 2008, Rassi et al. 2010). Drainage has also had a negative impact on many of the ecosystem services provided by natural peatland ecosystems. Although new ditches are no longer being dug in Finland's peatlands the state of our peatland habitats is still deteriorating due to the impacts of earlier drainage schemes.

The overall goal of peatland restoration is to enable the natural functions and structures of peatland ecosystems to become re-established in areas where they have been affected by human activity. Specific objectives may be achievable within several years (e.g. raising the water table level, Section 3), within several decades (e.g. the reappearance of near natural vegetation communities, Section 5), or perhaps only after centuries (e.g. the structure and dynamics of mature tree communities) (Aapala et al. 2008).

Restoration is not always necessary or recommendable. Restoration work could, for instance, endanger existing cultural or natural features including rare or threatened species that are sensitive to disturbance (Sections 8.1 and 9). Likewise, if valuable old-growth forest features such as abundant and diverse deadwood are present in a drained spruce mire, the benefits and drawbacks of restoration should be very carefully weighed up.

2.2 The ecological objectives of peatland restoration

The need for restoration and the prospects of success should be carefully evaluated for each peatland site before a decision is made to proceed (Section 6). As a basis for all peatland restoration work it is essential to understand both the structure and functioning of peatland ecosystems (Sections 3, 4, 5), and the various impacts of drainage and restoration measures.

The definition of detailed objectives for restoration work i is a vital part of any restoration project (Section 6). These objectives should be used to steer the planning, implementation and impact monitoring phases of the project. Objectives can be defined with help from historical records such as old aerial photographs and maps, as well as data on the present state of comparable natural peatlands as well as the site to be restored.

Hydrology

The structures and species communities of peatland ecosystems are largely determined by their hydrology, so restoration work must strive to re-establish an ecosystem's natural hydrological features as well as possible (Section 3). Each peatland site has its own hydrological characteristics affected by climatic factors as well as the physical and ecological features of its own basin and catchment area.

Goals typically include raising the water table back to near natural levels, and re-establishing natural flows of water through different parts of the mire, resulting in the restoration of naturally varying hydrological features (Sections 3 and 6). In addition to the damming of ditches, the restoration of hydrological features must also involve re-establishing the flows of water that would naturally feed the peatland ecosystem. This is particularly important in minerotrophic peatland sites (Section 3) whose characteristics are largely determined by the quality, quantity and timing of incoming water flows from their catchment areas.

Even poorly maintained ditches typically serve to drain water away so well that ditched peatlands no longer have the kinds of extensive flows of water in porous surface peat layers that characterise natural peatlands. Leaving a drained peatland to "revert by itself" to a natural state may lead to the development of a peatland ecosystem resembling for example a nutrient-poor pine mire, but is unlikely to promote the reappearance of the key features of wet and nutrient-rich peatlands. Active restoration measures are generally needed wherever the goal is to restore natural hydrological processes in a peatland site.

Flora and fauna

The key goals behind peatland restoration are to halt the decline in peatland species (Figure 5) and to trigger a process of ecological succession that will re-establish the near natural functioning of peatland ecosystems. Many potentially restorable drained Finnish peatlands still have sphagnum mosses and other key peat-forming plants that play an essential role in the natural functions of peatlands and in the recovery of other species communities (Sections 4 and 5). But peatland vegetation can only recover effectively if natural or near natural hydrological conditions are restored (Section 3).

Detailed species-specific objectives can be defined for restoration projects: the goal may be to enable typical species to return to a certain part of the peatland, or to manage the habitat of a specific threatened or otherwise significant species (Section 8, Info box 5). Wherever such objectives are specified it is important to consider the respective species' habitat requirements, the location of the site in relation to potential source populations, factors that could limit the species' spread, and factors related to competition between and within species (Mälson & Rydin 2007, Mälson et al. 2008). It is especially important to understand the prospects for species' survival in nutrient-rich peatland habitats, so as to ensure that species still present will continue to survive in spite

Figure 5. *Many peatland butterflies are highly dependent on natural conditions in their habitats, and they quickly vanish from drained peatlands. The frigga fritillary (Clossiana frigga) has generally declined across Finland due to the widespread drainage of peatlands, but just recently the species has begun to reappear in restored peatlands.* PHOTO: JUSSI MURTOSAARI.

of the disturbance caused by restoration work (Sections 8.1 and 11.1).

The changes in species communities induced by drainage are often so drastic that it is impossible to define detailed species-related objectives. Nutrient-rich and wet peatlands particularly change rapidly and greatly after ditches are dug, and few traces of their original natural species communities may be evident (Figure 6). However, peatlands do also evolve naturally over time due to external and internal factors. The goal of restoration should not be to restore the site to its exact condition before drainage, but to strive to trigger a process through which the site will become a peatland ecosystem with near natural functions.

Figure 6. *The species communities of this eutrophic pine fen have changed completely since drainage ditches were dug. The site will be restored by damming ditches and felling and removing the trees that have grown since the ditches were dug. This site lies downstream of natural and previously restored eutrophic pine fen habitat, so it should be possible for some of the original species to return successfully after the site is restored.* PHOTO: SARI KAARTINEN

2.3 Other objectives

It may be possible to restore lost or weakened ecosystem services in restored peatlands, and this goal has recently been raised alongside promoting biodiversity when defining objectives for restoration (Aronson et al. 2006, Society for Ecological Restoration International 2008, Benayas et al. 2009, Kimmel & Mander 2010, Bain et al. 2011, Bullock et al. 2011). The Finnish ecosystem-based approach to peatland restoration also helps to re-establish and reinforce the ecosystem services provided by peatlands.

The most significant of the regulating ecosystem services provided by peatlands in global terms is climate regulation. Mitigating climate change is accordingly one of the goals of peatland restoration (Info box 3). Regulating ecosystem services that are important on a more local scale include water flow and water quality regulation; and peatland restoration also aims to re-establish and enhance these services (Section 3). In the short term nutrients may leach from restored peatlands (Section 6.4, Info box 4), but in the longer term restoration improves the quality of runoff from peatlands.

Drainage also changes the whole landscape. Another goal of restoration is to recreate the natural structural features of the landscape, including areas of open peatland (Figure 7). Landscape restoration goals usually also align with other cultural ecosystem services provided by peatlands, such as recreational amenity value. Hunting is a popular recreational activity in Finland's peatlands, and the restoration of game bird habitats has become an important objective for many restoration projects (Info box 5).

Figure 7. *Restoration work was realised in Haapasuo Bog in Leivonmäki National Park in Central Finland in 2001. The pine trees that had grown on originally open parts of the bog (photo A) were removed before the ditches were blocked. Photo B shows the same part of the bog four years after the trees had been felled and the ditches dammed.* PHOTOS: ANNELI SUIKKI.

The climate impacts of drained and restored peatlands

Eeva-Stiina Tuittila and Jukka Laine

From a climate perspective natural northern peatlands have three important functions: they account for about a third of worldwide soil carbon storage; they fix more carbon dioxide from the atmosphere than they emit; and they account for some 20–30% of annual global methane emissions (Gorham 1991, Turunen et al. 2002, Lafleur et al. 2003, Nilsson et al. 2008). Drainage alters the role played by peatlands in regulating the global climate. A water level drawdown triggers a drying succession in vegetation and microbe communities (Laine et al. 1995b, Jaatinen et al. 2007). When decomposition processes are no longer limited by the lack of oxygen (Fenner & Freeman 2011), soil organic matter (SOM) previously accumulated in anaerobic conditions below the water table starts to decompose more rapidly (Pitkänen et al. 2013), and consequently more carbon dioxide is released into the atmosphere (Martikainen et al. 1995). It is likely that all drained peatlands become net carbon sources for a period of time soon after drainage, before the successional changes in their vegetation start to compensate for the carbon released due to decomposition. These successional changes, which commonly include accelerated tree growth, alter decomposition rates by favouring plant species that produce slowly-decaying litter on the soil surface. Following the drainage succession some peatlands drained for forestry end up functioning as small carbon sinks, while others continue acting as carbon sources (Ojanen et al. 2010, 2012, Lohila et al. 2011). This variation in the carbon sink function is related to nutrient levels and climatic factors: nutrient-rich drained peatlands in Southern Finland are more often carbon sources than nutrient-poor drained peatlands in Northern Finland (Ojanen et al. 2010, 2012). Concurrently with changes in vegetation and carbon dioxide fluxes methane emissions from drained peatlands decline due to a decrease in methane production and increased oxidation. Drained peatlands may even act as small-scale methane sinks (Roulet et al. 1993, Yrjälä et al. 2011).

Raising water table levels as part of peatland restoration slows aerobic decomposition and reduces carbon dioxide emissions, thus stabilising carbon stores and finally turning the peatland back into a net carbon sink (Komulainen et al. 1999, Tuittila et al. 1999, Wilson et al. 2007, Waddington et al. 2010). The restoration succession towards the vegetation and carbon sink functioning typical of pristine peatlands appears to progress faster in nutrient-rich peatland sites than in nutrient-poor sites (Komulainen et al. 1999). However, since nutrient-rich sites are more radically changed by drainage in the initial phase of restoration they are typically further from their natural state than nutrient-poor peatlands, where natural conditions can be re-established more rapidly. Although the restoration succession in vegetation communities promoted by the raising of water table levels (Haapalehto et al. 2010, Laine et al. 2011) is thought to make restored peatlands into relatively small annual carbon sinks similar to natural peatlands, considerable levels of carbon sequestration have been measured in restored former peat extraction sites during the first years after water levels rise (Soini et al. 2010) (Figure 8). While raising the level of the water table reduces carbon dioxide emissions, higher water table levels conversely increase methane emissions (Waddington & Day 2007). Recent research findings indicate that methane emissions from restored peatlands previously drained for forestry remain low more than ten years after restoration. These low emissions have been linked to the low abundance of methane-producing microbes and changes in their microbial community structure (Juottonen et al. 2012). It appears that the natural methane cycle recovers more slowly than the carbon sink function, and that the recovery of the microbial community plays a key role in the re-establishment of the methane cycle.

Figure 8. *Measuring carbon dioxide flows in a restored fen. The amounts of carbon absorbed and released can be measured using closed chambers.* PHOTO: JUKKA LAINE.

The impacts of peatland restoration on water quality

Tapani Sallantaus

Peatland restoration projects aim to re-establish natural processes such as nutrient cycles and the accumulation of nutrients in new peat layers. This in turn is expected to improve the quality of runoff water from restored peatlands, compared to runoff from peatlands with functioning drainage ditches.

Over a short timeframe the raised water tables caused by blocking ditches represent a radical change in conditions for the trees, other vegetation and soil organisms present in drained peatlands. Drainage changes the characteristics of surface peat layers, affecting decomposition, and releasing nutrients for growing vegetation to utilise. Restoration work may initially induce pronounced changes in the quality of runoff.

On the basis of findings from the monitoring of a total of 15 catchment areas and nine separate monitoring sites, a set of reasonably reliable specific load figures can be obtained for restored sites, quantifying the additional leaching of phosphorus, nitrogen and organic carbon into watercourses due to restoration per area of restored peatland. These elements are the leached substances most clearly affected by peatland restoration. Specific loads describing the additional leaching caused by a specific measure, in this case peatland restoration, can only be calculated when all impacts have become evident. In the 15 catchment areas studied, post-restoration monitoring was conducted for an average of 7 years. Prolonging the monitoring period would only have improved the specific load data slightly.

The sites monitored included very different kinds of peatland ecosystem. The peatland sites monitored in five catchment areas in Seitseminen National Park are mainly ombrotrophic or slightly minerotrophic. They were originally sparsely wooded pine mires where ditches had been dug about 30 years previously, with phosphoric fertilisers spread after drainage. Tree cover still remained limited before restoration, with an average of 55 m^3/ha of timber, and the undergrowth still contained many peatland species, including sphagnum mosses (Section 11.7, Koskinen et al. 2011, Sallantaus & Koskinen 2012). Two of the catchment areas included a single lake, with retention times of approximately 0.3 years in each case. The restoration sites at Haapasuo in Leivonmäki National Park (Section 11.5) and parts of the sites at Punassuo are also nutrient-poor pine mires. Restoration has mainly been successful in these nutrient-poor sites (Figure 7, page 10).

More densely wooded nutrient-rich spruce mires were monitored in three catchment areas at Mustakorpi in Nuuksio National Park (Koskinen et al. 2011, Sallantaus & Koskinen 2012) and in the catchment area of Lake Vähä-Ruuhijärvi in Evo. Before restoration these sites had quite dense forest cover, mainly spruce trees, with timber volumes as high as 300 m^3/ha or more in places; and their vegetation communities were mainly similar to those of heathland forests (herb-rich drained peatland forest or *Vaccinium myrtillus* drained peatland forest) (Figure 9). Parts of Mustakorpi had been drained more than 60 years previous to restoration.

Figure 9. *After being drained, this site at Mustakorpi developed into a peatland forest characterised by large spruce trees.* PHOTO: TAPANI SALLANTAUS

Figure 10. *After restoration nutrient-rich peatland vegetation has gained ground in Mustakorpi and many large trees have died.* PHOTO: TAPANI SALLANTAUS

During restoration work trees were not removed, but waterlogging caused deaths of trees and other pronounced changes in vegetation (Figure 10). The retention time of Lake Vähä-Ruuhijärvi is almost a year.

The northernmost monitoring site, at Suuripää, represents rich fens (Räinä 2010). Provisionally usable data on water quality is also available from a rich fen site at Huppionvuori (Section 11.1). The other sites, at Vanneskorpi (Sallantaus et al. 1998, Väänänen et al. 2008, Vikman et al. 2010), Konilammensuo (Silvan et al. 2005), and Hepo-oja (Lehtelä 2005), are fairly nutrient-poor sites where vegetation communities exhibit characteristics intermediate between pine mires and spruce mires.

Table 1 shows the findings from the best documented sites. Phosphorus loads were high for the nutrient-poor pine mires in Seitseminen and for nutrient-rich spruce mire sites. Haapasuo had the lowest specific loads, though the quantities leached at Suuripää were also low.

Specific loads at nutrient-poor Punassuo are similar to those observed in Seitseminen. Vanneskorpi had high figures for leaching and the highest specific loads among all the data (Sallantaus et al. 1998), while specific loads were lowest at Konilammensuo and Hepo-oja (not shown in the table).

The loads of the three water quality factors are interrelated, but specific loads of nitrogen and organic carbon are proportionally larger in relation to phosphorus loads in more nutrient-rich peatland sites. It is particularly significant that a considerable part of the nitrogen mobilised in nutrient-rich mires is inorganic, e.g. about a quarter at Mustakorpi, but just a few per cent in nutrient-poor sites such as Seitseminen.

In five separate areas out of nine specific loads were significant and of the same scale as those caused by first-time drainage or forest regeneration (Section 3.4), or sometimes even higher for phosphorus. The sites with high loads are both nutrient-rich and nutrient-poor. The high specific loads at Vanneskorpi can be explained by the peatland site's very extensive catchment area, which results in large flows of water that have effectively leached available nutrients out of the peatland site.

Table 1. *Specific loads of nutrients additionally leached due to peatland restoration at the best documented sites. n = number of catchments. Imprecise values are italicised.*

	Total P kg/ha	Total N kg/ha	Organic C kg/ha	n	ref
Seitseminen	2.6	14	700	3	Koskinen et al. 2011
Seitseminen lakes	3.6	14	560	2	
Mustakorpi	1.7	22	900	1	Koskinen et al. 2011
Vähä Ruuhijärvi	3.5	9	340	1	
Haapasuo	*0.1*	*0.6*	*30*	1	Section 11.5
Suuripää	*0.7*	*4*	*100*	1	Räinä 2010

Of the sites with low load figures, the peatlands at Konilammensuo, at Hepo-oja, and in parts of Haapasuo are all rich in iron. The abundance of iron is known to be a highly significant factor regulating the leaching of phosphorus (Zak et al. 2010) and organic carbon (Knorr 2013). At Konilammensuo logging residues were carefully removed, but this was also generally done at the sites in Seitseminen. The forest fertilisation realised after the sites in Seitseminen were originally drained may account for the high figures for phosphorus leaching. At the three northernmost sites the figures for leaching were low, reflecting both the cooler climate, and the fact that conditions in the peatlands had not changed as radically since drainage as in more southerly sites.

The impacts of any lakes in the catchment area on specific loads seem to be limited, though loads of nitrogen and organic carbon seem to be lower in relation to phosphorus loads as a consequence of lacustrine processes including decomposition and sedimentation.

By the end of the monitoring period at many sites loads had returned to almost their pre-restoration levels. The longest monitoring period continued until ten years after restoration. In Seitseminen phosphorus leaching peaked at high levels 1–2 years after restoration, but then decreased rapidly. In the spruce mire sites at Mustakorpi and Vähä Ruuhijärvi evapotranspiration from trees kept the peatland sites dry even though ditches had been blocked, so the period of increased leaching was prolonged.

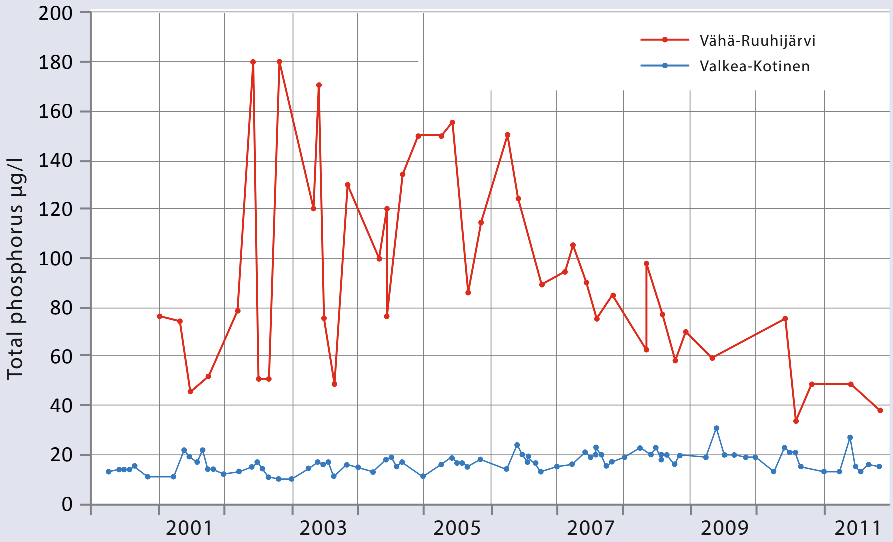


Figure 11. *Total phosphorus concentrations in the surface waters of Vähä-Ruuhijärvi and Valkea-Kotinen, 2000–2011. Peatland restoration work was realised in about a fifth of the catchment area of Lake Vähä-Ruuhijärvi in 2001. Valkea-Kotinen is a nearby lake whose catchment area is completely in its natural state. Initial concentrations in Lake Vähä-Ruuhijärvi were already higher than normal since a beaver dam had earlier raised its water levels. Valkea-Kotinen: concentrations at a depth of 1 metre. Vähä-Ruuhijärvi: concentrations either at a depth of 1 metre or in the stream channel that drains the lake (average figures when concentrations were measured in both locations).*

Pronounced load peaks occurred after wet years until several years after restoration. Increases in post-restoration leaching levels were clearly more prolonged for organic substances and nitrogen than for phosphorus (Koskinen et al. 2011).

The impacts observed in lakes downstream were completely different in the nutrient-poor sites in Seitseminen when compared to impacts affecting the nutrient-rich spruce mire sites at Vähä-Ruuhijärvi. In both cases phosphorus concentrations rose after a brief time-lag to more than 100 µg/l, but under the acidic conditions prevalent in Seitseminen the lack of nitrogen prevented eutrophication, and A-chlorophyll concentrations were never higher than 14 µg/l. In the catchment area of Lake Vähä-Ruuhijärvi, which is characterised by spruce mires, restoration also mobilised nitrogen, and phosphorus concentrations of more than 70 µg/l were still observed annually in the lake seven years after restoration. Phosphorus concentrations returned to pre-restoration levels in just under 10 years (Figure 11).

Conclusions

The most serious water quality problem triggered by peatland restoration concerns the risk of a steep increase in phosphorus leaching. This phenomenon occurred in more than half of the sites monitored. It is not easy to predict where worryingly high downstream loads will occur. Enhancing predictability in order to prevent negative impacts would be an important area for future studies. This is an issue that does not only affect peatlands in protected areas, since commercial forestry is likely to be abandoned in many areas of unproductive drained peatlands around Finland, and the active restoration of their peatland ecosystems is one alternative for their future management.

Restoring the habitats of willow grouse and other game birds

Ahti Putaala

Populations of willow grouse (*Lagopus lagopus*) in the boreal zone of Finland have been declining over the last 30 years. In the south willow grouse have vanished from many areas, and their remaining populations are isolated. This trend is thought to be due primarily to the decline and degradation of their natural habitat caused by the drainage of peatlands. As the climate becomes milder the shorter snowy season and consequent increased predation could also be speeding their decline.

The conservation and recovery of willow grouse populations can be promoted by restoring the peatland habitats where they mate and breed. In commercially managed forests owned by the Finnish State selected areas where willow grouse and wild geese breed are routinely restored as part of normal forestry operations. Measures are also taken to restore small, drained wetland hollows and spruce mires surrounded by heathland forests, so as to provide suitable habitat where game birds can raise their young. These measures have been financed using income from the sale of hunting permits for State lands.

By the end of 2012 a total area of about 2,400 hectares of willow grouse peatland habitat had been restored, mainly consisting of nutrient-poor pine bogs. The restoration methods used are the same as for peatlands in protected areas. Relatively minor additional resources are required for planning and implementing such work, since measures can be realised together with other more routine forestry operations. Ditches in areas to be restored can for instance be blocked at the same time as ditches are cleared and maintained in nearby areas not designated for restoration.

The suitability of restored peatland sites for willow grouse has been studied by tracking and mapping the spring territories of radio-tagged birds. New spring territories have been occupied in restored sites, and other restored peatland sites have also been used for nesting and raising young fledglings (Figure 12).

Figure 12. *This male willow grouse has established his spring courtship territory in a restored peatland site.* PHOTO: TIMO ESKOLA.

3 The hydrology of peatlands

Sakari Rehell, Tapani Sallantaus, Teemu Tahvanainen, Tuomas Haapalehto and Samuli Joensuu

3.1 Water table levels and the origins of peatland water

The water present in peatlands consists of water that has fallen onto them as precipitation and water that has flown into them from surrounding areas as runoff (Figure 13). The characteristics and functioning of minerotrophic peatlands are always connected to conditions in their catchment areas, i.e. the surrounding areas from where runoff flows towards the peatland. It is essential to examine the hydrology of the whole catchment area when planning peatland restoration projects (Section 6.1).

Naturally flowing waters can be divided into surface water, soil water and groundwater. Surface water may form temporary or permanent ponds, flarks, pools and rivulets. Groundwater fills pores in the ground and bedrock. Soil water consists of water kept in the soil by capillary action as well as water percolating downwards due to gravity. Peatlands particularly contain a lot of capillary water, especially in decomposed peat. Capillary water commonly rises in peat by at least a metre (Päivänen 1973). In well-decomposed peat water only moves very slowly, whether by capillary action or due to gravity. This slow movement of water can affect the availability of water to plants.

In natural peatlands the water table lies near the surface of the peat, and the seasonal variations in the water table and total water reserves are usually relatively small. If the soil below a peatland is highly permeable to water then the water table may fluctuate more.

3.2 Water flows in peatlands

Water flows through peatlands as surface runoff, in pores in the peat, and in the ground beneath the peat.

Surface runoff mainly occurs during flood peaks, in Finland most notably during the spring thaw. During the growing season water flows in peatlands mainly occur in the pores within the peat. These flows determine the conditions for peatland vegetation.

In the ground beneath the peat water flows according to the gradient of the water table, and flows are stronger where the ground is more permeable. Groundwater flows are limited in the poorly permeable moraine soils predominant in Finland. This means that water flowing in from the peatland's catchment area largely flows through the peat. Where runoff water from the catchment area flows through fairly permeable soils or underground streams beneath the peat then it does not significantly affect the peatland vegetation.

3.3 Water quality in peatlands

The precipitation that falls onto peatlands and the runoff that flows into them from surrounding areas have quite different chemical properties. Rainwater and snow contain very low concentrations of dissolved substances, and natural precipitation is slightly acidic. Runoff flowing through soil gradually dissolves carbon dioxide, mineral-ions and acidic organic substances.

The characteristics of the soil affect the concentrations of dissolved minerals. In areas with moraine soils most of the runoff entering peatlands arrives during the spring thaw or periods of heavy rain, when a lot of water moves through the topsoil. During such wet spells the concentrations of alkali cations are lowest, but organic substances, iron and aluminium are all leached from the topsoil. In areas with permeable soil no runoff flows through the topsoil, and the organic substances leached from the topsoil into the recharging water are retained in the illuviated soil horizon together with iron and aluminium.

Similarly in areas with moraine soils some precipitation percolates down into the groundwater. Groundwater may discharge into peatlands in places, reflected in the presence of demanding plant species. If easily soluble calcium-rich minerals are present, calcium concentrations in groundwater may rise steeply, reflected in the occurrence of plant species that thrive in (or can tolerate) high levels of calcium. Similarly groundwater may in some areas contain high concentrations of magnesium or sodium, which affect the peatland vegetation in the same way as calcium (Tahvanainen 2004).

In anoxic soil layers iron is dissolved in soil water. It then precipitates in springs or flarks where groundwater is discharged into peatlands. Concentrations of the key nutrients nitrogen and phosphorus are

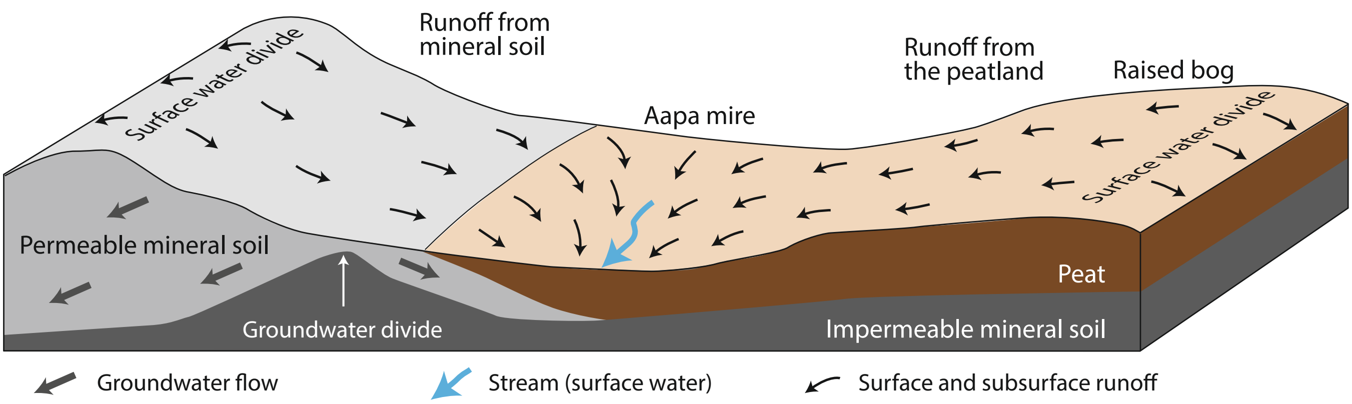
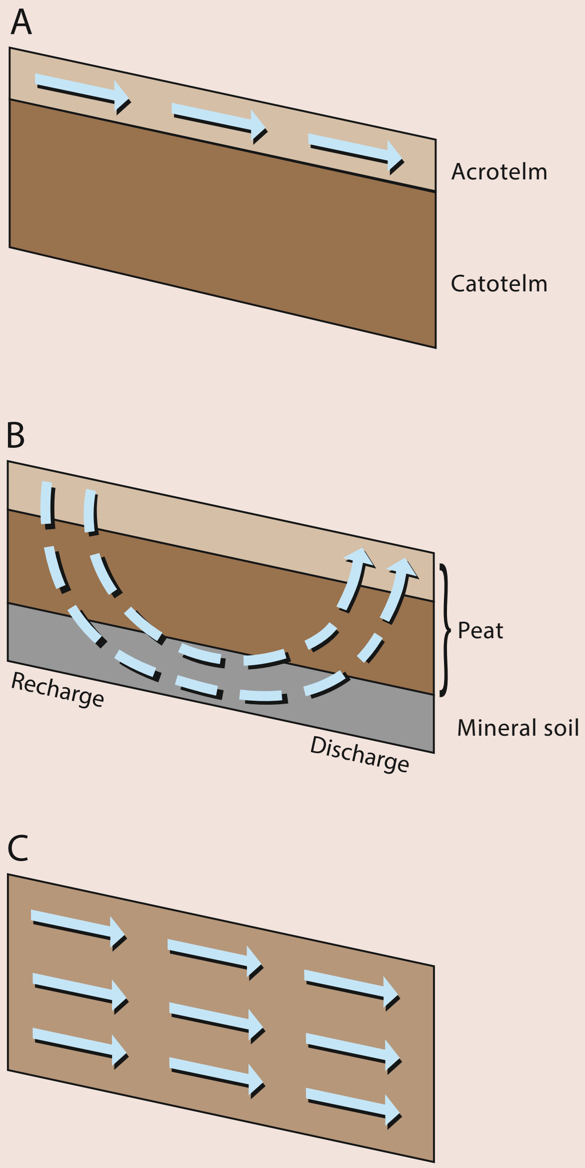


Figure 13. *Flows of surface runoff and groundwater, and the locations of surface water and groundwater divides.*



FLOW MODELS FOR PEATLAND WATER

The permeability of peat layers determines where water flows are concentrated. Three simplified models are used to help describe complex flow systems: A) diplotelmic model; B) peatland integrated into groundwater flows; C) percolation model.

A) Most peatlands in the boreal zone can be well described using the diplotelmic model (Ivanov 1981, Ingram 1983, Laitinen et al. 2007), which has two clearly distinct layers of peat. The surface peat layer (acrotelm) is porous and highly permeable to water. The sub-surface peat layer (catotelm) is denser and only slightly permeable to water. This model assumes that no water flows through the catotelm, meaning that all the water flows through the acrotelm according to the gradient of the water table in the peatland. The acrotelm has a self-regulating mechanism. When water is abundant, the water table rises and outflows intensify. When there is less water, the water table drops to the lower boundary of the acrotelm, and outflows decline, eventually to zero.

The diplotelmic model has particularly been devised to describe the hydrology of raised bogs, but its basic assumptions can be considered as applying to most of Finland's peatlands. Although in aapa mires and raised bogs with many flarks the surface may largely consist of exposed peat, with no diplotelmic structure, variations in the water levels in the areas of exposed peat are largely regulated by elongated hummocks whose structure is diplotelmic.

B) Peatlands integrated into groundwater flows. Water flows through such peatlands as part of the wider recharging and discharging of groundwater, with flows also occurring vertically between peat layers and the ground beneath (Laitinen et al. 2008). In areas where the groundwater is recharged water flows downwards through the peat, while in areas where groundwater is discharged it rises up towards the surface.

C) In percolation mires water flows through thick layers of porous peat. True percolation mires (Joosten & Clarke 2002) are rare in Finland. But spring-fed or swamp fens with evidently thick layers of permeable surface peat and a permeable sub-surface layer of sedge peat typically exhibit water flows that resemble those in percolation mires.

usually low in natural groundwater, where nitrogen levels are often lower than in rainwater.

The movements of water and water quality are closely interlinked. Peatlands capture and store chemical elements from the water that flows through them by means of biological and chemical processes. These substances accumulate in peat, but at the same time substances including organic acids formed during the partial decomposition of plant matter are dissolved into the water from the peat, significantly affecting water acidity (Hemond 1980, Tahvanainen et al. 2002). The stronger the flow of water through a peatland, the faster organic acids will be leached out of the peat. The pH of the water is the result of the balance between organic acid concentrations, mineral alkalinity and carbon dioxide. The pH of the water is the chemical characteristic most closely linked to the development of vegetation communities (Tahvanainen 2004). High mineral concentrations in groundwater, for instance in calcareous fens, increase the alkalinity of the water and effectively neutralise the effects of organic acids even when water inflows are more limited.

Mosses are the best indicators of water quality among peatland plants. Moss species assemblages are indicative of trophic levels, which particularly reflect the pH of the water. At the ombrotrophic end of the scale, where nutrient levels are lowest, are raised bogs, which only receive water from precipitation. The pH level of the water in raised bogs is usually less than 4.2, and calcium concentrations are lower than 0.5 mg/l. Moss communities include species tolerant of acidic conditions, such as sphagnum moss species associated with nutrient-poor peatlands. It is noteworthy, however, that no sphagnum moss species is limited exclusively to ombrotrophic peatlands.

In minerotrophic peatlands the water contains varying quantities of dissolved minerals originating from areas with mineral soils. At the nutrient-poor end of the minerotrophic range, in oligotrophic peatlands, vegetation communities and water chemistry do not differ much from those in ombrotrophic peatlands (Tahvanainen et al. 2002). It should be noted that sedges indicative of minerotrophic conditions may also occur in peatlands that are ombrotrophic in terms of the chemistry of their surface water, if the sedge roots are able to reach deeper, more minerotrophic peat layers (Tahvanainen 2011).

In mesotrophic peatlands and in rich fens, plants requiring high pH levels thrive, while species more associated with nutrient-poor conditions are absent or only occur in hummocks or other locations away from inflowing water. Concentrations of dissolved minerals and pH levels are both higher than in peatlands with lower trophic levels. In oligotrophic conditions pH values are typically under 5, while in mesotrophic conditions they are 4.5–6. The water in rich fens is often almost neutral, though pH values may vary between 5.5 and 8.5. The pH values observable under differing trophic conditions thus overlap considerably. One reason for this is fluctuations in carbon dioxide concentrations, which lead to variation in pH values even at different times of day (Tahvanainen & Tuomaala 2003). There is also considerable overlap for other chemical indicators of trophic levels, such as calcium concentrations, as well as sizeable variations between different nutrient levels. Rich fen vegetation sometimes indicates calcium-rich conditions even at calcium concentrations as low as approx. 2 mg/l (Tahvanainen et al. 2002), though in rich fens in areas with truly calcium-rich conditions concentrations of more than 20 mg/l are common.

3.4 Impacts of drainage on peatland hydrology and loads in river basins

Drainage lowers the water table in the peat in order to promote tree growth by deepening the oxic soil horizon. The goal is typically to create a layer of aerated soil at least 40 cm deep (effective ditch depth) on the surface of the peatland (Päivänen & Hånell 2012).

Drainage schemes account for the natural flow directions of the water in the peatland. The main drainage ditch is often located in the lowest part of the peatland with the other feeder ditches entering it aligned diagonally with respect to the gradient of the

GROUNDWATER-FED PEATLANDS

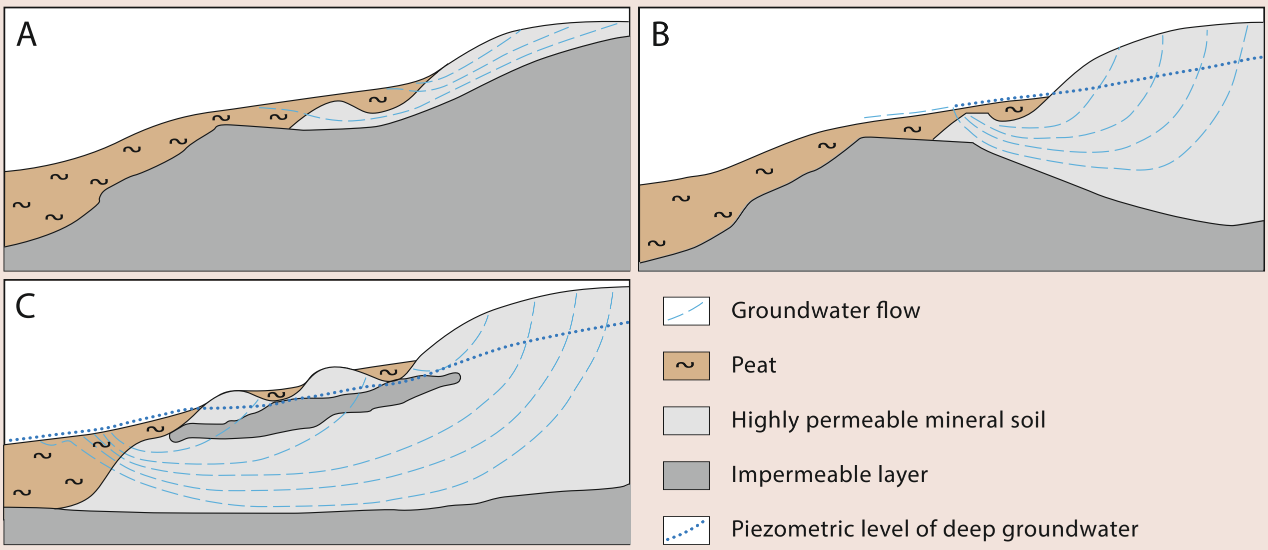
Where groundwater is formed in the peatland itself or is discharged to the peatland through the peat layer a three-dimensional approach needs to be applied when examining their hydrology (Heikkilä et al. 2001, Laitinen et al. 2007).

A) In Finland the terrain typically consists of a fairly thin layer of moraine deposits overlying gently undulating impermeable bedrock. Runoff from mineral soils flows on or near the surface. This water discharges into peatlands at the edge of the mineral soil, and only has a minor groundwater effect, typically limited to small seepage areas on the margins of mires. Defining the catchment area of this kind of peatland is a straightforward process, and such peatlands can be assumed to resemble the diplotelmic model.

B) One common feature in Finland is the immediate juxtaposition of a permeable esker formation bordering on a peatland with an impermeable base. Plenty of groundwater typically accumulates in eskers, since almost all precipitation rapidly percolates through their sandy soil into the groundwater. In elongated eskers groundwater may also flow long distances from where it is first accumulated. Groundwater is discharged from larger esker formations quite evenly all year round. Where it is discharged into a peatland it typically wells up in large open springs on the margin of the peatland and the mineral soil of the esker. This spring-water may flow onward as a stream, in which case the discharged groundwater may not be dispersed through the peatland at all.

Where peatlands are fed by groundwater from esker formations their hydrology differs greatly from conditions in areas with more typical moraine soils. They receive water throughout the growing season, so the peatland itself may also discharge plenty of water even during drier seasons.

C) In areas with deep soils exhibiting pronounced layering, such as ice marginal formations, groundwater may flow quite different distances in different soil layers (Heikkilä et al. 2001). Peatland ecosystems linked to such formations may be highly diverse. In some places water may well up to the surface, while elsewhere it may seep back down into the groundwater and flow for up to several kilometres through permeable ground layers. Many different types of peatland habitat may occur, ranging from spring fens and seasonal wetlands to rich birch fens. In such areas the impacts of different actions, including both drainage and restoration, may cover extensive areas and be hard to predict.



peatland to optimise drainage. Intercepting ditches are dug along the boundary between the peatland and the surrounding areas with mineral soils to intercept any surface runoff that would otherwise enter the peatland.

Drainage increases runoff rates. Larger quantities of water are discharged from the peatland, reflected in the drying out of the peat and the sinking of the surface. The total change in the quantity of water stored in the mire is most typically of the order of 300 – 400 mm, corresponding to a year or more of runoff. Increased runoff also reduces evaporation from drier peatlands. In drained, wet and sparsely wooded peatlands evaporation may initially decline by as much as hundreds of millimetres a year, and the increase in runoff compared to the situation before drainage may be prolonged for up to 20 years (Seuna 1981). Runoff particularly increases during periods of low runoff such as summer and midwinter.

The peat eventually becomes gradually denser and its diplotelmic structure disappears. As the permeability of the denser peat declines, variations in the water table become more pronounced (Päivänen 1973) and minimum runoff levels gradually decrease. Total runoff is primarily reduced by the increased evapotranspiration from trees.

Findings on the impacts of drainage on maximum runoff levels during monitoring periods are somewhat contradictory, but in general maximum runoff levels have been observed as increasing (Seuna 1981, 1982, 1988, Verry 1988, Sirin et al. 1991, Johansson & Seuna 1994, Holden et al. 2004). Although the impacts of tree cover in terms of evapotranspiration are significant, since for instance the evapotranspiration from 100 m^3 of growing timber in one hectare reduces water levels during the summer by an average of 20 cm (Lukin 1988, Vasander & Lindholm 1989), the risk of increased summer flooding can be considered as a permanent consequence of peatland drainage (Seuna 1981, Ahti 1987).

Drainage also significantly affects water quality. The impacts of drainage are intensified in minerotrophic peatlands that have developed due to inflows of water from their catchment area, where ditches intercept inflows from the catchment area. This water no longer recharges the peatland, inhibiting the ability of the peatland to filter various substances from the incoming water. Substances previously accumulated naturally by the peatland also begin to be leached away.

Specific loads in terms of increased leaching of newly drained peatland over a ten-year period have been measured at 1.6 kg/ha for phosphorus and 21 kg/ha for nitrogen (Ahtiainen & Huttunen 1999, Kenttämies 2006). The impacts of drainage do not end within ten years, however, since drainage results in permanent hydrochemical changes in processes in the catchment area. In older drained peatland areas monitoring has indicated that leaching of phosphorus and nitrogen increase respectively by factors of 3 and about 1.5 compared to natural catchment areas (Joensuu 2002, Kortelainen et al. 2006).

Nutrient leaching in drained peatlands is also increased by the clearing of older ditches, supplementary ditching, the felling of trees, and fertilisation. The specific loads of phosphorus and nitrogen caused by ditch clearances are lower than those induced when ditches are first dug (Joensuu 2002, Finér et al. 2010, Åström et al. 2001b, 2005). Specific loads induced during forest regeneration have been measured for phosphorus at 0.64 kg/ha and for nitrogen at 25.9 kg/ha (Finér et al. 2010).

Peatland drainage also affects the leaching of dissolved organic carbon (DOC) in many ways. Increased runoff promotes the leaching of DOC, but at the same time the reduced runoff through the surface peat layers reduces it (Sallantaus 1988). After drainage water flows occur deeper in the ground, which particularly in shallow peatlands may be reflected in lower DOC concentrations in runoff quite soon after first-time drainage or the re-clearing of drainage ditches (Hynninen & Sepponen 1983, Lundin 1988, Joensuu 2002, Åström et al. 2001a, 2005). Drainage nevertheless increases DOC concentrations in the surface layers of the peat, since organic material is no longer diluted or leached away by runoff from the catchment area (Sallantaus 1995). The long-term monitoring of river basins has not yet resulted in clear findings on the impacts of peatland drainage on downstream humus concentrations (Metsä- ja turvetalouden vesiensuojelutoimikunta 1988, Räike et al. 2012).

First-time drainage generally has a neutralising impact on the acidity of runoff (Heikurainen et al. 1978, Ramberg 1981, Hynninen & Sepponen 1983, Sallantaus 1983, Lundin 1987, 1988, Berry & Jeglum 1991, Manninen 1998, Ahtiainen & Huttunen 1999, Prévost et al. 1999). The re-clearing of drainage ditches has a similar impact (Joensuu 2002). In certain conditions, however, drainage may increase the acidity of runoff, at least occasionally, e.g. in sulphur-rich peatlands in areas with acid sulphate soils (Saarinen et al. 2013). If the peat layer throughout the area impacted by drainage is ombrotrophic, drainage does not increase pH values in runoff (Sallantaus 1983, 1992).

Drainage evidently acidifies the surface layer of peatlands (Lukkala 1929, Vahtera 1955). The most important process behind this acidification is an increase in concentrations of soluble humic material in the peatland groundwater. Humic substances leach variable cations from the peat into the peatland water and runoff, leading to a reduction in reserves of alkali cations in the peatland (Laiho & al. 1999, Haapalehto et al. 2014). The uptake of nutrients by growing trees also reduces nutrient levels in the peat.

Loads of suspended solids increase greatly where ditches are dug (Metsä- ja turvetalouden vesiensuojelutoimikunta 1988, Holden et al. 2004 & refs.). The consequent impacts have been more serious in smaller water bodies (Vuori et al. 1998). Current guidelines emphasise the need for measures to reduce the leaching of suspended solids, e.g. with the help of sedimentation ponds, overland flow areas, and buffer zones left alongside streams.

3.5 Impacts of restoration on peatland hydrology and loads in river basins

Peatland restoration usually raises the water table very rapidly (Tahvanainen 2006, Aapala & Tukia 2008, Autio 2008, Laine et al. 2011). During early peatland restoration work the most typical problem was that water flows continued to concentrate on the lines of the blocked ditches leaving the rest of the peatland too dry. In some cases measures were under-scaled, for instance where ditches were blocked only with individual dams and no peat embankments were constructed (e.g. Section 11.5). Restoration methods have been subsequently improved over more than 20 years, but restoring natural hydrological conditions to peatlands still cannot be considered as a straightforward process where success can be assured.

Excessive waterlogging is seldom problematic in restored peatlands. Such problems may however arise in spruce mires and spring-fed areas, or where water is fed into peatlands in point locations or from wider areas than would be natural.

The chances of success in restoration projects are better where conditions have not changed so much since the peatland was drained. In drained nutrient-poor peatlands still covered by continuous sphagnum moss growth, for instance, the structure of the acrotelm layer regulating hydrological conditions will probably revert to near natural conditions relatively rapidly. The presence of well-defined elongated hummocky strings also improves the prospects for success, since such features reinforce the effects of dams, and raised water levels will often be sufficient to restore natural functions in areas that originally had exposed peat or limited sphagnum moss growth. Conversely it is more difficult to restore natural hydrological conditions in peatlands that have changed greatly since they were drained, and therefore lost their original peatland vegetation and the natural structural features of surface peat layers. Such peatlands were often naturally nutrient-rich, sloping sites with abundant through-flows of water.

The redevelopment of peatlands' natural hydrology and vegetation are closely interconnected: hydrological conditions will only be effectively restored where the main features of the vegetation are re-established, and vice versa. Infilled ditches typically remain wet with little vegetation cover after restoration work. Particularly where water flows continue to follow the lines of ditches moisture conditions may vary greatly, and the accumulation of surface peat may be much slower on infilled ditches compared to the areas between ditches, meaning that the old ditch channels will continue to be lower-lying. Especially in nutrient-rich peatlands with pronounced flows of water, the channels of former drainage ditches may remain permanently evident after restoration if too few peat embankments have been constructed or they do not function well.

One of the goals of restoration is to re-establish the natural hydrological functioning of the entire peatland complex. Though completely natural hydrological conditions may not be restorable in all parts of a peatland, even deficiently restored parts may play an important role in terms of efforts to re-establish the hydrology of the whole complex. Even the poorly restored margins of aapa mires, for instance, may be crucial if they can channel water through to parts of the undrained peatland that had dried out. Such measures can thus halt the deterioration of peatland ecosystems even far away from the restored area. Impacts may be particularly extensive where water tables are raised in peatlands overlying highly permeable sand or gravel.

Little data is available on the impacts of restoration on runoff and its variability. In principle these impacts should be the opposite of the impacts of drainage. After restoration a peatland becomes waterlogged: the water table rises, dry peat becomes wet, and the surface rises as the peat swells. The effective ditch depth is relatively small, and the increase in the water reserves in the peatland caused by restoration generally only reduces runoff compared to pre-drainage levels during the year restoration is realised. The longer-term impacts of restoration on runoff depend significantly on trends in evaporation. In sparsely wooded peatlands evapotranspiration from trees is limited, and evaporation from the newly waterlogged ground and proliferating vegetation will most likely increase, reducing runoff. Where tree cover is denser, the way tree stands are managed or otherwise develop after restoration can have a crucial impact on changes in total runoff. Reducing tree cover also reduces evaporation, but increasing the areas of wet surfaces has the opposite effect.

Many studies have shown that peatland drainage can also increase maximum runoff levels (Ahti 1987, Seuna 1981, Holden et al. 2004), so these levels are likely to decline after restoration.

When ditches are blocked water levels rise and vegetation dies. Runoff from the catchment areas of minerotrophic peatlands spreads through them, leaching the peat. These trends may all have harmful impacts on water quality in aquatic ecosystems downstream (Info box 4). The most serious water protection problem relates to the increased leaching of phosphorus. This has been observed in many monitored restoration sites.

Any harmful downstream impacts will most seriously endanger small water bodies. Water bodies downstream of restored sites may also be negatively affected by the impacts of forestry work. The specific loads caused by forestry measures are typically about as large as or even larger than those induced during restoration work (Finér et al. 2010, Kenttämies 2006, Section 3.4 and Info box 4).

It is very difficult to completely avoid such negative impacts, since the substances involved are dissolved in water. Carrying out work over a longer period at different times is one possible solution.

Some restoration sites do not generate any significant loads, however, and restoration may improve the state of downstream water courses immediately after measures are realised. Restoring the drained margins of aapa mires, for instance is likely to improve the quality of downstream water bodies, while also evening out flood peaks, since water from the catchment area will be redirected along its natural routes into the undrained central parts of the mire, instead of by-passing the mire in drainage ditches.

In the longer term restoration can be expected to affect the quality of runoff positively. There is evidence of this from various studies, including one in the British Isles, where peatland restoration was found to have improved water quality and boosted biodiversity in streams and rivers downstream (Ramchunder et al. 2012).

4 Surface peat and peat formation

Teemu Tahvanainen and
Tuomas Haapalehto

4.1 Peat formation in natural peatlands

Peat forms when dead parts of plants remain partly decomposed in water-saturated anoxic conditions. Peat accumulates wherever the dead plant matter decomposes more slowly than new plant matter grows. In sphagnum bogs, for instance, sphagnum moss often grows at a rate of several centimetres a year. The rate of peat accumulation is on average much less than this, however, since lower peat layers decompose and become more densely packed. The average rate of peat accumulation in peatlands in Finland has been estimated at 0.3 mm a year, and the highest rates of long-term accumulation are around 3 mm a year (Mäkilä 2006). Although peat only accumulates slowly, it plays a highly significant role in the global carbon cycle. About 90% of its total weight consists of water, but carbon accounts for about 50% of its dry weight. It has been estimated that the peat in all the peatlands of the Northern Hemisphere contains some 547 petagrammes of carbon (Yu 2011; Pg = 10^{15} g), amounting to about 40% of all the carbon stored in soils around the world, and corresponding to about 70% of the carbon dioxide in the atmosphere. According to more cautious estimates, boreal peatlands contain 275–455 Pg of carbon (Turunen et al. 2002).

Sphagnum mosses annually produce on average 150–320 grammes (dry weight) of biomass per square metre, corresponding to 75–160 grammes of carbon (Lindholm & Vasander 1990). Peatlands dominated by sedges usually have higher productivity, though it can generally be stated that peatlands are not particularly productive environments, and peat formation is not a direct consequence of biomass production. The rate of peat accumulation is instead crucially dependent on the rate of biomass decomposition. The factors that limit decomposition play an extremely important role in peat formation. Most of the organic matter in a peatland decomposes in the oxic surface layer of peat, known as the acrotelm (see page 17: flow models, the acrotelm and the catotelm). Decomposition progresses particularly rapidly in the lower part of the acrotelm, near the water table. In the peat layers below the acrotelm, known as the catotelm, decomposition is considerably slower. The key stage of peat formation can be considered as the phase when the partly decomposed organic matter becomes part of the catotelm.

Natural peatlands in Finland typically accumulate about 10–30 grammes of carbon per square metre per year. In raised bogs the long-term carbon accumulation rate averages 21 g/m^2/year, while in minerotrophic peatlands the average rate is 17 g/m^2 (Turunen et al. 2002). The annual accumulation rates are larger when shorter time periods are considered. This is because peat decomposition continues at a very slow rate also in the catotelm in older peat deposits. Shorter-term accumulation rates are useful for instance when comparing the changes recently induced by drainage and restoration.

In sphagnum bogs new layers of sphagnum peat form on top of older layers. Peat formed from sedges contrastingly consists largely of the remains of the roots of sedges. Since these roots extend deep into the peat, sedge peat does not exhibit such clear chronological layering as sphagnum peat. But it is still possible in principle to define an acrotelm in the surface layer of sedge peat where various processes occur before the peat becomes part of the deeper catotelm and enters longer term "storage". Peatland drainage and restoration both affect the regulation of water levels most clearly in the surface peat layers, thus shifting the boundary between the acrotelm and the catotelm. In deeper peat layers the impacts of drainage and restoration are much less evident.

4.2 The dynamics of peat decomposition

The decomposition of plant matter is affected by the characteristics of the plant matter itself and by the conditions for decomposition. Peatlands are unique environments where the formation of peat is favoured by conditions that slow the decomposition of plant matter. The most important of these conditions is a shortage of oxygen due to wetness. Decomposition rapidly consumes oxygen in the water that fills the pores in peat layers, and since water only flows through peat slowly, oxygen cannot effectively reach the catotelmic peat layers beneath the water table from more aerated surface peat layers. Anoxic conditions are widespread in peatlands in water-saturated pores even above the water table. On the other hand, vascular plant roots extending deep into the peat can transport oxygen and break the boundary between the peat layers formed by the water table, where oxygen is available. The volume and speed of water through-flow also affect the availability of oxygen.

In addition to anoxicity, decomposition is often limited by acidity, by shortages of nitrogen and other nutrients and minerals, and by the comparatively low temperatures typical in lower peat layers. Moreover, sphagnum mosses in particular have biochemical properties that also evidently slow decomposition. In deep raised bogs many factors combine to slow decomposition: all nutrients are in short supply, pH levels are low, the insulating surface layer of peat keeps temperatures low in deeper layers, there are few plants with deep roots that could transport oxygen, and a large part of the plant biomass consists of poorly decomposing sphagnum mosses. In aapa mires peat usually decomposes faster than in raised bogs, and peat layers are shallower, because nutrients are more available, pH levels are higher, greater through-flows of water and the abundance of sedge roots both increase the availability of oxygen for decomposers, and the plant biomass itself is more easily decomposed.

Plant matter is decomposed through a series of biochemical reactions catalysed by many different enzymes. In peatlands anoxicity and acidity both reduce the activity of the phenol oxidase enzymes that catalyse the oxygenation of phenol (aromatic) organic compounds (Freeman et al. 2004). This increases phenol concentrations in organic substances, since the oxygenation of phenolic compounds is inhibited. High phenol concentrations in turn slow or prevent the action of other enzymes in the decomposition chain. Low pH levels are also known to limit phenol oxidase (Tahvanainen & Haraguchi 2012), and in nutrient-poor peatlands shortages of nitrogen also reduce the activity of phenol oxidase (Bragazza et al. 2006). Contrastingly, high concentrations of iron, for instance may promote the oxygenation of phenol even where oxygen is in short supply (van Bogedom et al. 2005).

Rates of decomposition and thus peat formation can be affected by many different factors where conditions change due to drainage or restoration.

4.3 The impacts of drainage on peat formation

Intensive peatland drainage effectively stops peat accumulation. Though litter still forms on drained peatlands as vegetation dies, it no longer ends up in a water-saturated catotelm, which can be considered as a precondition for peat formation. The surface peat layer above the catotelm in drained mires consists of fresh litter together with old peat formed before drainage. The thickening of the oxic surface peat layer of the acrotelm promotes decomposition. Additionally, the surface peat layers tend to sink greatly due to the loss of the water that previously caused them to swell. As the peat decomposes and sinks it also becomes denser, reducing its porosity and permeability to water.

In the topmost layer of the surface peat, formed of litter from trees and other forest vegetation, water cannot easily rise through capillary forces. The hydrological properties of the surface peat layer thus changes considerably due to the impacts of drainage (Päivänen 1973), and the same is true of its chemical properties. After drainage pH levels in the peat usually decline, and concentrations of the main cations (Ca, Mg, K and Na) also decrease due to increased leaching. Mineral concentrations are likewise not replenished, since minerotrophic water is transported away by drainage ditches and no longer feeds the peatland areas between ditches.

Although drainage effectively halts peat formation, the situation is not as clear when it comes to the accumulation of carbon. Drainage generally leads to increased decomposition in older peat, but carbon fixation increases overall due to changes in the vegetation, as more carbon is taken up by the biomass of trees and dwarf shrubs etc. Even discounting the timber that will be logged, the increased biomass of tree roots has great significance in the soil carbon balance. The carbon losses caused by drainage are greatest during the first years after drainage. Over time, changes in vegetation communities reduce these losses (Laiho et al. 2003) and other factors such as declining pH in the surface peat slow decomposition (Toberman et al. 2010). In drained peatlands temperatures in the peat are generally lower than in natural peatlands, due to increased shade from trees and the insulating effect of the thicker aerated surface peat layer (Laine et al. 2004). The net impact of these differing factors and their conflicting consequences can in principle be measured by observing changes in the amounts of carbon in the peat layers, or by measuring exchanges of the gases CO_2 and CH_4 between the peatland and the atmosphere. In practice, however, it is difficult to obtain precise results on changes in carbon stocks and the carbon balance.

One way to get an overview of the overall impacts of drainage is to compare the amounts of carbon in peat layers of certain ages in drained and undrained peatlands. A comparison examining the carbon that has accumulated over the last 300 years in surface peat showed that in drained peatlands an average of 32 tonnes per hectare less carbon remains, compared to undrained peatlands (Mäkilä & Goslar 2008). This difference is due at least partly to the decomposition of older peat in drained peatlands, and the continued accumulation of new peat in undrained peatlands. If these figures for carbon loss are understood as representative at a national level, peatland drainage in Finland can be estimated to have caused a total loss of more than a hundred million tonnes of carbon from the surface peat of drained peatlands. However, the differences between the amounts of carbon in the surface peat of drained and undrained peatlands could also be related to original differences between the sites, since the peatlands chosen for drainage have typically been those with shallower peat deposits.

Several studies of the impacts of drainage on the carbon balance in surface peat have been conducted, but their results are to some extent conflicting. Minkkinen & Laine (1998) estimate that drainage increases the amount of carbon in peat by an average of 5.9 kg/m^2 over the whole of the period the peatland is drained. Their findings exhibited great variations, however, and many sites showed considerable carbon losses of up to 20 kg/m^2. The changes in the carbon stock depended on the volumes of timber and regional differences in temperatures. High carbon losses from drained peatlands have also been observed in more recent studies where peat deposits have been examined in sites that were also studied before drainage (Simola et al. 2012) or where carbon levels have been studied in peat samples from drained and undrained parts of the same peatland (Pitkänen et al. 2013). Studies of the annual balances of carbon gases indicate that net carbon loss occurs in nutrient-rich peatland types for decades after drainage, but that in drained nutrient-poor peatlands the soil acts as a carbon sink (Ojanen et al. 2013). In the peatland sites poorest in nutrients, i.e. drained raised bogs, tree stands generally do not develop, so tree litter cannot compensate for the carbon losses caused by increased decomposition. Studies generally do not account for the carbon fixation that would occur on the drained peatlands if they had been left in their natural state. The impacts of future forestry actions are also unknown, and it is possible that carbon losses from surface peat could increase due to the maintenance of drainage ditches, groundwork and fertilisation.

4.4 The impacts of restoration on peat formation

The development of peat-forming vegetation is a precondition for the formation of peat. Sphagnum mosses are of the greatest importance in this context. In areas where the peatland vegetation is dominated by sphagnum mosses it is possible to distinguish the moss growth that has developed since restoration, and the new surface peat formed from it, overlying the surface peat that formed while the peatland was still artificially drained (Figure 14).

Sphagnum moss often spread rapidly after restoration. In favourable conditions they may cover the whole surface within a few years, depending on factors such as the extent to which natural peatland plant species have survived in the site through the drainage period. Sphagnum mosses spread when their shoots branch. After sphagnum moss has spread over the surface of a peatland site it can be expected that the dying moss biomass will accumulate and form new sphagnum peat over time as it decomposes. It is almost impossible to draw a line to distinguish dead biomass (litter) and sphagnum peat; but it is possible to examine the new surface peat formed after restoration overall, including the topmost layer of living moss (Figure 14).

Observations of the accumulation of new surface peat have been made in many restored peatland sites (Tahvanainen 2006) and a comprehensive study of this issue is currently being conducted (Kareksela et al. 2013). Field surveys of the first restored peatlands, conducted ten years after restoration, revealed varying degrees of waterlogging in the peatland surfaces, with new surface peat being thicker where the water table had risen most (Tahvanainen 2006).

The accumulation of surface peat affects material flows in peatland ecosystems in many ways. The growth of peatland vegetation and the accumulation of surface peat both serve to fix carbon and nutrients. In fairly nutrient-poor pine mires in Central Finland the rates of annual carbon fixation in surface peat evidently increased to natural levels within ten years of restoration (Kareksela et al. 2013), largely due to the rapid growth of sphagnum mosses. The annual carbon fixation rate in new surface peat averaged about 108 g/m^2 over the first ten years. For a total restored area of 15,000 hectares of peatland the carbon fixed in this way would be the equivalent of almost 60,000 tonnes of carbon dioxide. Peatland restoration also affects the leaching of organic carbon and emissions of methane from peatlands. This could affect the climate impact of restoration even more than the sink effect of carbon fixation in surface peat (Info box 3).

In addition to impacting the carbon cycle, restoration also affects the chemical characteristics of the surface peat. Concentrations of Ca, K, Mg, Mn and P have been observed as rising back to levels observed in similar natural peatlands within about ten years of restoration (Haapalehto et al. 2010). In natural undrained peatlands these elements exhibit typical distribution patterns in peat layers at different depths (Damman 1978, Pakarinen 1978). Since the nutrients released from litter and root exudates are recycled by the living parts of peatland plants, the concentrations of many nutrients are highest in the uppermost part of the peat layer. This kind of natural depth distribution has been observed as returning, at least with respect to K and Mn concentrations, within ten years of restoration (Haapalehto et al. 2010). Such findings indicate that the nutrient cycle between plants and peat has become normalised.

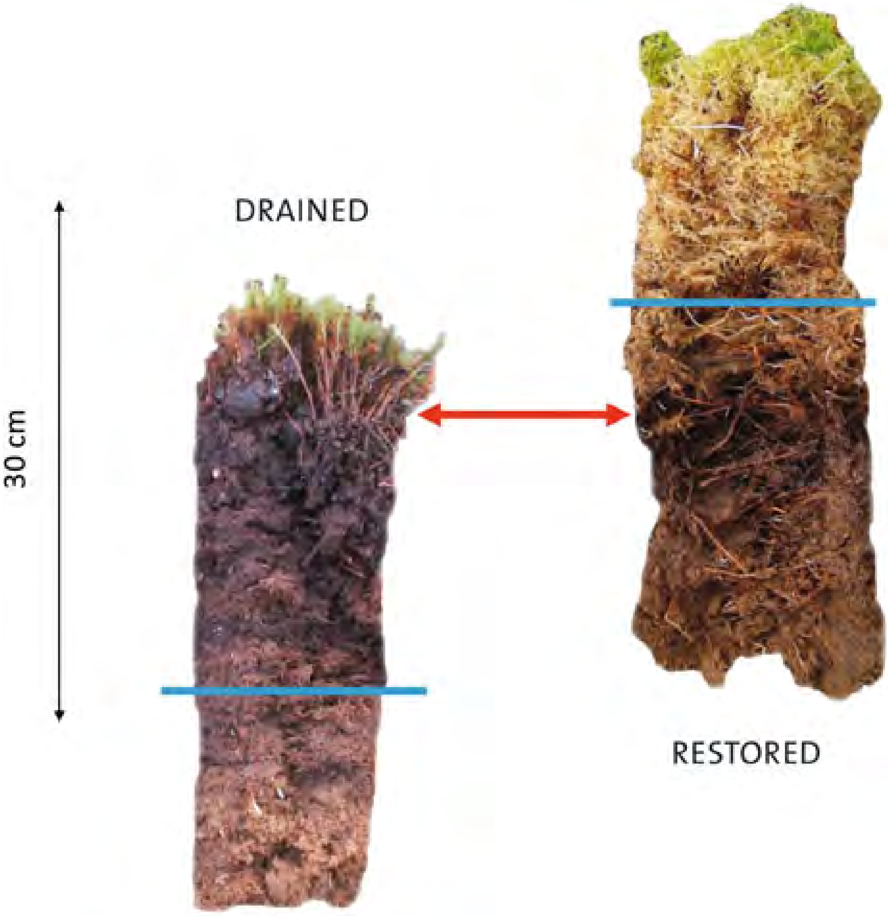


Figure 14. *In drained peatlands the surface peat decomposes and becomes denser above the water table level (blue line). Restoration aims to raise the water table to the surface of the peat (red arrow), increasing the abundance of sphagnum mosses. Within just ten years of restoration the sphagnum mosses may start to form new sphagnum peat, which will gradually accumulate in layers beneath the water table in relatively anoxic conditions. Both of these peat sections have as their lowest layer pale brown sphagnum peat that formed when the peatland was in its natural state. Even after restoration the impacts of the drained peatland forest stage can be seen as a darker layer between the pre-drainage and post-restoration sphagnum peat layers, containing remnants of pine needles, bark, cones, and forest mosses.* PHOTOS: TEEMU TAHVANAINEN.

5 Peatland biodiversity

*Kaisu Aapala, Sakari Rehell
and Maarit Similä*

Biodiversity encompasses the diversity of ecosystems, as well as species diversity and genetic diversity within species. In practical terms the most significant level of biodiversity is often considered to be species diversity, since this factor is comparatively easy to measure. In the wider context of preserving biodiversity the goal is to preserve the characteristic species assemblages characteristic of different habitats, rather than striving to maximise the number of species present in any single area.

In peatlands life must adapt to demanding conditions, since peatland habitats are permanently wet, which means that oxygen is absent or scarce, except in peat layers right at the surface. In nutrient-poor peatlands high acidity levels also limit the prospects for many species. Peatlands are often naturally relatively species-poor ecosystems, and their most significant values in terms of biodiversity are due to the habitats they provide for their species and species communities that do not occur in other habitats.

5.1 Diversity in peatland microbial communities

The diverse microbial communities of peatlands play a crucial role in the functioning of peatland ecosystems. Their species composition varies according to habitat characteristics including levels of moisture, oxygen, acidity and nutrients (Fisk et al. 2003, Rydin & Jeglum 2006, Wieder & Vitt 2006). Microbes particularly play a key role in the carbon cycle and in nutrient cycles, as well as in the decomposition of organic substances and the formation of peat (Laine et al. 2000, Pietiläinen et al. 2005, Vasander & Kettunen 2006, Info box 3).

The composition of microbial communities in peatlands is closely linked to the structures of their plant communities (Littlewood et al. 2010). Natural successional processes and disturbances caused by human activity, such as drainage or restoration, all significantly change the microbial communities of peatlands, as well as the structural features of their plant communities (Merilä et al. 2006, Jaatinen et al. 2007, 2008, Juottonen et al. 2012). The impacts of these changes are not yet understood in detail. The interrelationship between the diversity of microbial communities and the functions of peatlands in particular remains unclear. Likewise little is known about the significance of the recovery of natural microbial communities in the context of re-establishing the natural functions of restored peatlands.

5.2 Diversity in peatland plant communities

Plants are the most important functional species group in peatland ecosystems. Peatland plants shape their own habitat in an exceptional way, since they form their own growth substrate: peat. Plant communities also greatly affect biodiversity at the ecosystem and landscape level.

Variations in peatland vegetation are the result of many environmental factors, including the origins of the water that feeds the peatland, acidity levels (pH), the availability of main nutrients (nitrogen and phosphorus), the water table level, and the depth of the peat (Wheeler & Proctor 2000). Seasonal variations in moisture levels have also been observed as correlating with the composition of vegetation communities (Laitinen 2008).

5.2.1 Vascular plants

The vascular plants of peatland habitats can be divided into the functional groups: sedges, grasses, herbaceous plants, dwarf-shrubs, shrubs and trees. Sedges such as *Carex globularis*, *C. lasiocarpa*, *Eriophorum* spp., *Trichophorum cespitosum* and *Rhynchospora alba*, are typically the dominant species in fens, where they can form prolific growths (Figure 15). Grasses are typically found in peatlands slightly richer in nutrients, e.g. *Molinia caerulea* and *Phragmites australis* in rich fens and mesotrophic fens; or *Calamagrostis* spp. in herb-rich spruce mires. The species diversity of herbaceous plants on peatlands is typically fairly low. Herbaceous plants typically found in nutrient-poor peatlands include *Drosera* spp. and *Rubus*

Figure 15. *Plants found in this mesotrophic flark fen in Salamajärvi National Park include Carex lasiocarpa, Molinia caerulea and the early marsh orchid Dactylorhiza incarnata. In summer 2012 as many as 500 orchids flowered here.* PHOTO: REIJO HOKKANEN. →

Figure 16. *A natural tree stand in a stream-side mire in Suomussalmi.* PHOTO: SUVI HAAPALEHTO.

chamaemorus. The most diverse peatland habitats in terms of herbaceous plants are rich fens and nutrient-rich spruce mires. Peatland dwarf-shrubs mainly grow on hummocks, but *Vaccinium oxycoccos* and *Andromeda polifolia* can also thrive on the lawn level.

The characteristic features of natural spruce mires and pine mires include trees of varying sizes and ages (Figure 16). Trees affect the other vegetation in such habitats through shade and root competition. Decaying wood additionally provides important habitat for many species groups.

Of the vascular plant species found in Finland primarily in mires a total of 21 are nationally threatened and 11 are near threatened (Rassi et al. 2010). Regional red list surveys have additionally classified about 40 further peatland plant species as regionally threatened in Southern Finland (Ryttäri et al. 2012). Taken together this means that more than half (55%) of the plants primarily found in mires are threatened either in the south or across Finland.

5.2.2 Mosses

Peatland mosses can be categorised according to their ecological characteristics as: Sphagnum mosses, brown mosses, feather mosses and liverworts.

Sphagnum mosses (Figure 17) play a fundamental role in boreal peatland ecosystems. They can thrive in peatlands due to their adaptation to wet, acidic, anoxic and nutrient-poor habitats, which they themselves significantly shape (Rydin & Jeglum 2006, Rydin et al. 2006). Sphagnum mosses acidify their own habitat and keep it wet and anoxic (Rydin & Jeglum 2006). They can tolerate very low nutrient concentrations and thrive even in areas only fed by rainwater. Their ability to store water in their dead hyaline cells and transport it upwards through capillary action helps to maintain the high water tables in peatlands. Their varying rates of growth and decomposition (Rydin et al. 2006) and the interactions between sphagnum mosses and the sedge-like plants of the field layer (Malmer et al. 1994) also affect the formation and preservation of the smaller scale peatland landforms including hummocks, lawns, hollows and pools. Sphagnum mosses also play a significant role in the carbon cycles of boreal peatlands, since they effectively bind carbon and store it in the peat (Section 4).

Figure 17. *Colourful Sphagnum angustifolium, S. russowii and S. capillifolium on the surface of a palsa mire in Finnish Lapland, August 2012.* PHOTO: ELINA KOLPPANEN.

Sphagnum mosses are the dominant species in peatland vegetation, especially in nutrient-poor and acidic peatlands. Their species diversity is nevertheless highest in nutrient-poor and mesotrophic fens (Rydin & Jeglum 2006). Some species, such as *Sphagnum warnstorfii*, *S. contortum* and *S. teres*, also thrive in rich fens (Eurola et al. 1992, Laine et al. 2009).

Brown mosses are not a taxonomically defined group, but a group of species defined by their ecological characteristics, found most commonly in rich fens (Figure 18). Brown moss species include *Scorpidium cossonii*, *S. scorpioides*, *Loeskypnum badium*, *Campylium stellatum*, *Tomentypnum nitens* and *Paludella* *squarrosa*. The occurrence of brown mosses indicates that nutrients are available to some degree, and pH levels are higher than usual for peatlands.

Feather mosses, such as *Pleurozium schreberi*, *Hylocomium splendens* and *Ptilium crista-castrensis* commonly occur on drier surfaces such as higher hummocks and tree bases in natural peatland forest habitats.

Liverworts are often found growing as individual shoots among other mosses. Many of the threatened liverwort species associated with spruce mires require the continuing presence of deadwood at various stages of decay, as well as evenly moist microclimates and shady growth sites (Laaka-Lindberg et al. 2009).

Most of the red-listed moss species primarily found in peatland habitats are particularly associated with rich fens or spring-fed meso-eutrophic peatlands, though spruce mires also constitute important habitat for many of them.

5.3 Trends in the vegetation communities of drained peatlands

Artificial drainage changes the key characteristics of peatland habitats by reducing the amounts of water entering the peatland, speeding the outflows of water, changing the routes of water flows, altering the properties of the surface peat and increasing the depth of the oxic surface layer (Sections 3 and 4). This inevitably leads to many kinds of changes in peatland vegetation communities.

Lowered water tables even out the internal variations within growth sites, as well as the hydrological variations between different growth sites (Laine & Vanha-Majamaa 1992). This reduces the diversity of peatland vegetation and favours forest plant species. The first species to decline and vanish are those that thrive on wet lawn and flark levels. The plants associated with drier hummocks may be able to adapt to changing conditions, and initially even benefit from drainage. Later the growth of tree stands and increased shade will limit their opportunities to thrive. More mature tree stands will also lose more water through evapotranspiration, increasing the drying-out effect.

The speed of the changes occurring after drainage will depend on factors including nutrient and moisture levels, the effectiveness of the drainage ditches and the rate of tree growth (Laine & Vanha-Majamaa 1992, Laine et al. 1995b). In dryish and nutrient-poor peatlands typical plant species may survive for long periods after drainage (Reinikainen 1984, Vasander 1984, Laine et al. 2012), while wetter and more nutrient-rich peatlands tend to be changed more rapidly and fundamentally (Mälson et al. 2008, Laine et al. 2012). Other forestry measures implemented, such as fertilisation and thinnings, also affect the surviving vegetation (Vasander 1984, Hotanen 2003). The use of ash as fertiliser particularly leads to changes in the chemical and physical characteristics of the surface peat that may be pronounced and permanent, so changes in vegetation after ash fertilisation may also be great (Laine et al. 2012). In logged sites and seedling stands in peatland forests more light becomes available, favouring species that can thrive in sunlit habitats, such as *Eriophorum angustifolium*, *Rubus idaeus*, various grasses, and in nutrient-poorer peatlands also *Carex globularis* and *Eriophorum vaginatum* (Laine et al. 2012). If sphagnum mosses remain in an area, they may also temporarily become more abundant after logging when the water table rises (Laine et al. 2012).

Figure 18. *Scorpidium scorpioides growing in a flark in a rich fen. Karstula 2011.* sPHOTO: HANNU NOUSIAINEN.

5.4 Trends in the vegetation communities of restored peatlands

Restoration also radically changes the habitats of peatland plants: the water table usually rises rapidly and the oxic surface layer becomes shallower or disappears altogether. If trees are felled and removed the availability of light increases and nutrients become available to plants in the field and ground layers.

The state of the peatland before restoration has a direct impact on the speed of its recovery. Drainage generally leads to more radical changes in peatlands that were originally wet or nutrient-rich, compared to sites that were naturally dry or nutrient-poor. Evidence suggests that the recovery rate for nutrient-poor peatlands is initially slower than for nutrient-richer sites, but since the changes caused by drainage have typically been less dramatic in nutrient-poor peatlands, in the medium term restored nutrient-poor peatlands may revert back to a near natural state more rapidly than nutrient-rich peatlands (Kangasjärvi 2006).

During the initial stages of the post-restoration vegetation succession it is typical that certain species rapidly become much more abundant (Figure 19) (Komulainen et al. 1998, 1999, Kangasjärvi 2006, Mälson et al. 2008, Haapalehto et al. 2010, Hedberg et al. 2012).

The recovery of sphagnum moss growths is the essential first step

Figure 19. *Cotton-grasses can readily utilise the nutrients released in connection with peatland restoration, and they proliferate in many restored peatland sites for a few years after restoration. This photograph was taken two years after this site was restored.* PHOTO: MAARIT SIMILÄ.

towards the re-establishment of natural conditions in most restored peatlands. This process is generally triggered quickly, and sphagnum mosses can quite easily spread over areas with lichen cover or bare ground covered with litter (Kangasjärvi 2006, Aapala & Tukia 2008, Haapalehto et al. 2010, Bellamy et al. 2012).

Changes in the vegetation of rich fens often progress rapidly after drainage, and by the time restoration is planned rich fen species may have vanished from a site. The return of rich fen species can be hindered by the presence of dominant ground vegetation species (rich fen species compete poorly in comarisone with such dominant species), the absence of any seed bank or local source areas (dispersal barriers), or differences between the characteristics of the surface peat layers in the restored rich fen compared to those in natural rich fens (unsuitable substrate) (Mälson et al. 2008, Hedberg et al 2012). In some cases there may also be a risk that the "wrong kind of water" (nutrient-poor or acidic) may flow into restored nutrient-rich rich fens if it is not possible to recreate natural water flow pathways, or if drainage schemes outside the restored site have affected water quality.

Even though the forest species that earlier benefited from drainage will become less abundant, and the coverage of peatland plant species will increase after restoration, restored peatland sites will still probably continue to differ from corresponding natural peatlands for many years. Some species found in natural peatlands or on wet surfaces may remain absent, the total coverage of sphagnum moss may remain low, and species assemblages may remain somewhere between those of drained peatlands and those of natural peatlands.

5.5 Diversity in peatland fauna

Environmental factors affecting the diversity of peatland fauna include the structure of the vegetation (for nutrition, shelter and habitat), variations in the distribution of wet surfaces and drier hummocks, the amounts of open water, acidity levels, the density or absence of tree cover (light and microclimate), the quantities and kinds of decaying wood, and the total extent of the peatland ecosystem (Desrochers & van Duinen 2006).

The breeding birds found in peatlands particularly include many wader species. These birds favour large, open peatlands. Peatlands are rich in invertebrates, providing food for waders and their young. Peatlands in Finland are also important habitats for bean geese (*Anser fabalis*), game birds and certain birds-of-prey. They also provide important resting and feeding areas for migrating birds.

Peatland ponds, pools and flarks (Figure 20) provide good habitat and breeding sites for amphibians and many insect groups, including dragonflies. Crane flies also thrive in wet peatland conditions (Figure 21).

↑ ***Figure 20.*** *The perch (Perca fluviatilis) is a common fish species in peatland ponds and lakes in Finland. Isolated populations may occur in ponds without connecting streams.* PHOTO: JARI ILMONEN

← ***Figure 21.*** *The crane fly species Tipula melanoceros is common in peatland habitats including nutrient-poor fens and subarctic wetlands. Adults fly in August and September. They produce a single brood of eggs, which hatch into overwintering larvae. Tipula larvae largely feed on detritus, but they may occasionally eat other invertebrates.* PHOTO: JOUNI PENTTINEN

↑ ***Figure 22.*** *The golden-ringed dragonfly (Cordulegaster boltonii) is a large and striking insect often seen hovering over streams in forests and peatlands.* PHOTO: JARI ILMONEN

↓ ***Figure 23.*** *Frigga's fritillary (Clossiana frigga) can be seen flying in sparsely wooded pine mires in early summer. Its caterpillars live on cloudberry plants (Rubus chamaemorus).* PHOTO: JUSSI MURTOSAARI

The density or absence of tree cover is a key habitat characteristic for many peatland insect species. Peatland butterflies particularly favour sparsely wooded pine mires (Figure 23), whereas adult dragonflies (Figure 22) hunt for their prey in open, sunlit habitats.

For species dependent on decaying wood the quantities and quality of decaying wood and the continuing availability of sufficient decaying wood of suitable quality are all crucial factors in peatland habitats such as spruce mires, just as they are in forest habitats.

Drainage drastically changes the characteristics of the habitats of peatland fauna. The bean goose, for instance, has clearly suffered from the impacts of peatland drainage around Finland. Several passerine bird species that nest in peatlands have also become scarcer, including yellow wagtail (*Motacilla flava*) and rustic bunting (*Emberiza rustica*). Drainage similarly weakens the conditions for specialist peatland invertebrates, while improving the prospects for more generalist species from surrounding areas to expand their ranges (Laine et al. 1995a).

Of the threatened fauna primarily associated with peatland habitats the greatest number of species are butterflies and moths, with 19 species (Rassi et al. 2010). Peatlands additionally provide a significant viable habitat option for dozens of red-listed species from other groups including Diptera, Homoptera, arachnids, birds and beetles (Rassi et al. 2010).

For animal species that have vanished from a drained peatland to be able to re-establish themselves, viable source populations must remain in the vicinity, and the species must be able to physically return to the area after it has been restored. In sites where human activity has fragmented habitat mosaics it may even be necessary to artificially reintroduce populations of species that have vanished from a drained site.

5.6 Diversity in peatland habitats

5.6.1 Mire types

In Finland peatlands are classified on the basis of their degree of tree cover and their other vegetation into seven main categories (Kaakinen et al. 2008, Laine et al. 2012):

Spruce mires are wooded peatlands where the dominant tree species is usually Norway spruce, though deciduous trees may also grow abundantly in spruce mires that are richer in nutrients. The presence of living and dead trees of different sizes and ages is an important structural feature for the species-diversity of spruce mires.

In nutrient-rich spruce mires the vegetation in the field layer is species-rich and dominated by grasses and herbaceous plants. In nutrient-poor spruce mires vascular plant species assemblages are quite limited and dominated by dwarf shrubs associated with forest habitats. The ground layer is dominated by sphagnum mosses, though in more nutrient-rich sites other bryophytes may also be common.

Spruce-birch fens and rich spruce-birch fens have low hummocks where small, stunted trees grow. The dominant tree species is usually white birch, or in rich sites Norway spruce. Birches may also grow on lawns, and hummocks may be quite indistinct. Species associated with swamps may grow alongside fen and rich fen species in the lawn level, which is usually considerably more extensive than hummocks.

In pine mires and bogs hummocks dominate the microtopography of the surface. Such ecosystems are mainly nutrient-poor and usually have deep peat layers. The dominant tree species is Scots pine, though Norway spruce also thrives in higher sites. The dominant species in the field layer are dwarf shrubs. Sedges and herbaceous plants tend to be scarce, though the herb *Rubus chamaemorus* may be abundant and in certain types of pine mire *Eriophorum vaginatum* and *Carex globularis* are also abundant. The ground layer is largely composed of sphagnum mosses.

Pine fens and rich pine fens have a mixture of hummocks where pine mire vegetation dominates, whereas plants typical of fens or rich fens dominate lawns and flarks. A wide spectrum of nutrient levels is possible, from ombrotophic ridge-hollow pine bogs to rich pine fens. Tree stands are often sparse and stunted, or absent altogether in Northern Finland. The dominant tree species is generally pine, though birches may also be present or even abundant, and small spruces may grow in places.

Fens are mainly open peatlands with deep peat deposits, lawns and flarks. Their nutrient levels may range from ombrotrophic to minerotrophic. The field layer vegetation is characterised by sedges and herbaceous plants, with few dwarf shrubs. The ground layer consists of sphagnum mosses or other bryophytes, depending on the type, though fens of the mud-bottom flark fen type have hardly any moss.

Rich fens are neutral or mildly acidic, open or sparsely wooded peatlands. They are typically found in areas where the bedrock and soil are rich in calcium, though they may occur in other areas sufficiently influenced by groundwater. Their vascular plant and moss communities have high species diversity. Many threatened species are found in rich fen habitats. As many as half of Finland's threatened peatland species are primarily associated with rich fens (Rassi et al. 2010).

Swamps are typically found beside open water, and they are characterised by the continuous impacts of surface water bodies. Due to the continuing inflows of water, swamps are nutrient-rich and highly productive ecosystems. They host aquatic plants and shore plants as well as peatland species. Their vegetation differs from shore and aquatic vegetation due to the presence of a peat layer, but the dividing line can shift easily. There may be many herbaceous plants, and the field layer features sizeable plants and is often very dense. The moss cover in the ground layer may have many gaps, and be sparse or absent altogether, or it may consist of bryophyte species indicative of swamp conditions. Swamp habitats can be open, wooded or dominated by shrubs.

5.6.2 Mire complex types

Raised bogs are ombrotrophic mire complexes, i.e. the vegetation in their central parts obtains water and nutrients exclusively from precipitation and dry deposition from the air.

The central parts of a raised bog are usually higher than the rest of the peatland complex, and sparsely wooded or open. The margins of raised bogs are often very wet. Since they receive water from both the raised part of the bog and the surrounding areas with mineral soils, their vegetation is minerotrophic.

In raised bogs the hummocks typically form elongated ridges. Between these ridges lie moister hollows and pools of open water. Elongated hummocks and hollows are formed perpendicular to the gradient of the bog surface and the flow direction of the bog water (Figure 24).

↓ ***Figure 24.*** *This extensive concentric raised bog is in the Kauhaneva-Pohjankangas National Park. A pond has formed in its highest part. In ridge-hollow pine bogs, elongated hummocky ridges alternate with elongated hollows or open pools.* PHOTO: JARI ILMONEN / METSÄHALLITUS.

If drainage has not led to great changes in the vegetation and hydrology of the central parts of a raised bog, typical vegetation communities may be able to become re-established soon after restoration, especially if the bog's original structural features (hummocks and hollows) have survived. However, dense networks of drainage ditches and fertilisation may lead to radical changes in the vegetation of raised bogs, as in other peatlands, destroying their original microtopography.

Aapa mires are mire complexes with minerotrophic central parts and usually deep peat deposits. They may be flat or sloping. Nutrient levels in their vegetation may range from oligotrophic to eutrophic. In the open central parts of a typical aapa mire the microtopography features watery flarks alternating with drier hummock or lawn level strings aligned perpendicular to the water flow direction.

The margins of aapa mires are characterised by pine mires. Near areas with mineral soil and stream banks spruce mires may also be found. Between the marginal zone and the open central areas a transitional zone of pine fens or birch fens is commonly found.

In hilly regions of Eastern and Northern Finland and on the high arctic fells of Finnish Lapland sloping fens with quite steep gradients can be found, often fed by springs.

Drainage ditches dug in the margins of aapa mires can change their hydrology extensively downstream of the drained area, since water that earlier fed the mire is instead channelled past it in ditches. The impacts of drainage in aapa mires whose margins have been drained may be considerably more extensive and significant in the undrained central parts of the complex than in the drained areas themselves. Reduced water flows may lead over the decades to nutrient impoverishment and the proliferation of sphagnum mosses (Tahvanainen 2011).

The positive impacts of restoring the drained margins of aapa mires may be considerably more widespread than the extent of the restored areas, since after restoration water is again able to flow into the undrained but in practice dried-out and nutrient-impoverished central parts of the mire complex.

6 Planning peatland restoration projects

Sakari Rehell, Maarit Similä, Pekka Vesterinen, Jari Ilmonen and Suvi Haapalehto

Peatland restoration measures must always be carefully planned in advance. The restoration plan should describe the present state of the site, define the need for measures, set out objectives, assess the feasibility of their realisation, outline the means to be applied, and define how impacts will be monitored.

6.1 The present state of the site to be restored

6.1.1 Investigating natural and changed hydrological conditions

When planning a peatland restoration project the most important factor to assess is the entire catchment area, since this determines the hydrological conditions (Figure 25, Section 3). The catchment area is delineated by surface water divides, i.e. ridges of higher land that divide two areas where the surface water runoff flows in different directions (Figure 13, p. 16). If it is not possible to restore the whole catchment area, e.g. due to land ownership issues, the benefits of "partial restoration" should be carefully considered.

The flows of water in a peatland are also affected by small water bodies in the catchment area, natural flow paths, and any drainage ditches dug in the catchment area. Drainage ditches can even reshape the boundaries of catchment areas (Figure 25). In planning the restoration of hydrological conditions it is important to also evaluate the amounts of groundwater formed and discharged, the location of groundwater impacts, and whether the peatland is still effectively connected to all of its natural water sources (Section 3).

A peatland's original water flow paths and directions can best be determined by examining the contours on maps (Figure 25) and aerial photographs taken before drainage (Figure 72, p. 72). The microtopography of the surface of the peatland also indicates flow directions, since hummocky strings form perpendicular to the prevailing flow direction. The locations of springs, seepage areas and streams may also be discernible on older aerial photographs (Figures 72 and 73, p. 72).

Recent aerial photographs of open or sparsely wooded peatland areas reveal current moisture conditions and the locations of flowing water, thresholds and basins. Comparing old and new aerial photographs usually gives a reasonable picture of the changes that have occurred in a peatland's hydrology and vegetation (Section 11.5 and 11.7). It is important to identify the locations of thresholds that regulate water levels in larger areas (e.g. thresholds formed by mineral soil, or string formations) which can be restored to raise water levels suitably. Studies of aerial photographs and maps should determine which locations need to be examined in the field.

In the field the flow directions of ditches should be surveyed during wet periods, but discharges of groundwater or the smaller-scale impacts of springs are best observed during drier periods when upwelling water is more visible. If water is observed flowing in ditches during a dry period it is always worth investigating its origins.

Seepage of groundwater is often revealed by the occurrence in ditch bottoms or elsewhere of plant species associated with springs, which typically require mesotrophic or meso-eutrophic growth sites.

6.1.2 Data on species

Restoration plans should include an evaluation of the expected impacts of restoration measures on threatened species and a plan for the monitoring of their occurrences. If the aim is to use species monitoring to indicate the impacts of restoration, comparable drained and natural control sites where the same species occur, but where no restoration measures have been realised, should also be monitored.

It is important to understand the ecological requirements of the species concerned. The risk that a threatened species could decline or vanish as a consequence of higher water levels is greatest for rare species whose moisture level requirements are very strict. Examples include the species of peatland lawns that have shifted their distribution to dried-out flarks. Species associated with springs that may have shifted their distributions from springs or seepage areas to ditch bottoms due to drainage may also sometimes be sensitive to water level rises (Sections 11.2 and 11.3). As water levels rise the availability of the main nutrients may also increase, meaning that species associated with springs, rich fens or nutrient-poor peatlands could lose out to more common generalist species in the competition for growth sites. Species that thrive in swamps are best able to tolerate rises in water levels.

When restoring the habitats of threatened species it is important to have a good understanding of the most common restoration methods means and the ecological implications of restoration so that measures can be applied as needed in specific sites. Species-centred restoration planning is conducted at a considerably smaller scale than other kinds of restoration plans.

It could be necessary to assess whether restoration is possible at all in cases where measures could have negative impacts on the occurrences or growth sites of threatened species. In some cases the gradual phasing of restoration measures or the transplanting of threatened species within the peatland to be restored could reduce the risk of an occurrence being lost (Figure 26).

In Natura 2000 sites the occurrences of any species or biotopes listed in EU directives should be surveyed in addition to any threatened species and other significant species which could be affected by the planned restoration measures positively or negatively.

6.2 Defining objectives

Definitions of the ecological and biological objectives of restoration measures form a crucial element of any restoration

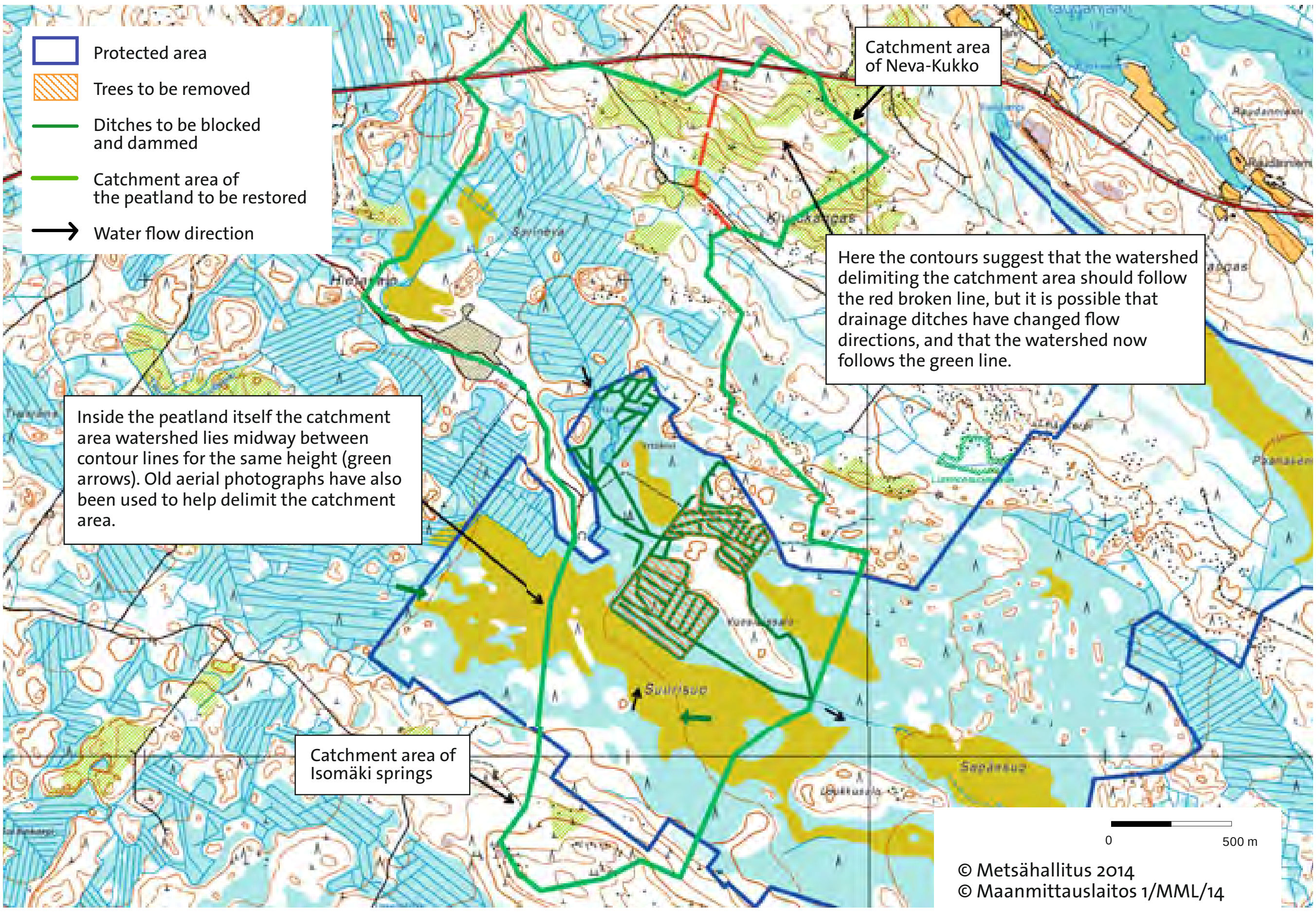


Figure 25. *Defining the catchment area of a peatland.*

plan (Section 2). In protected peatlands the goal is usually to re-establish ecological processes and water flows that are as near as possible to the site's natural conditions. This will enable peatland plants and other organisms to return or become more abundant again in areas earlier affected by drainage.

Where peatlands are restored in areas used for commercial forestry, the objectives may differ from those selected for peatland restoration projects in protected areas. Other goals in addition to the re-establishment of natural processes may include improved habitat conditions for game species, water protection goals, flood prevention, and enhanced conditions for the recreational use of the peatland.

6.3 Planning restoration measures

The restoration plan should set out in sufficient detail the measures to be carried out (Section 7) and how they will be implemented in practice. The most common measures include:

- Clearing trees along the banks of drainage ditches (Section 7.1)
- Removing trees or ring-barking standing trees to reduce evaporation from the trees (Section 7.2)
- Blocking, damming and infilling drainage ditches (Section 7.3)
- Diverting water flows (Section 7.3)
- Increasing the amounts of decaying wood, e.g. in spruce mires or in the adjoining margins of areas with mineral soil (Section 7.4).

During the planning stage it is important to identify potentially problematic aspects of a restoration project. Where necessary detailed surveys of a site's relief should be conducted, e.g. aiming to limit waterlogging impacts to areas within the peatland to be restored, or to define a suitable height for dams. Suitable methods include levelling surveys, laser level surveys and the use of laser scanning data.

In addition to the areas where measures will be realised, surveys should also cover other areas that will be directly affected by restoration measures even though no measures are realised within them.

6.4 Considering impacts in watercourses downstream

When planning restoration it is important to evaluate the scale of impacts on watercourses and water bodies lying downstream, since restoration may lead to harmful downstream impacts (Section 3.5, Info box 4).

The leaching of nutrients and suspended solids can be reduced by diverting water from the drainage ditches to be blocked onto the surrounding peatland. Such work should start from the higher parts of the catchment area, so that solids and nutrients remain in the peatland and do not enter watercourses downstream. This also improves the outcome of the restoration, since redirecting the water in this way helps to waterlog the peatland more evenly.

If the surface area of the peatland to be restored amounts to less than 15% of the total area of the catchment area of

Figure 26. The need to transplant species most often arises in Finland when restoring ground-water-fed peatlands or rich fens where threatened or otherwise valuable plant species grow on the beds or banks of ditches. Marsh saxifrages (Saxifraga hirculus) were transplanted in suitable growth sites in this restored rich fen in Northern Finland. PHOTOS: MARKKU PERNU.

the nearest recipient water body, restoration does not usually lead to intolerable harmful impacts on water quality and aquatic organisms at the scale of the whole watercourse. However, if the part of the watercourse downstream of the restoration site is sensitive due to the occurrence of salmonids or other threatened species, even short-term localised negative impacts could be harmful. When restoring more extensive areas of peatland in the same catchment area it may be worth dividing the restoration work up into sufficiently small stages realised over a longer time period, so that annual loads of suspended solids and nutrients remain tolerable.

When blocking ditches that lead directly into downstream watercourses the lowest parts of ditches should be left untouched, at least in the flood zone. The lowest-lying ditches above the flood zone should be blocked with sufficiently large dams built together with peat embankments, and reinforced with geotextile if needed, to ensure that water from the area being restored is channelled as surface runoff before entering the recipient watercourse. If significant amounts of water are flowing directly into the recipient watercourse from the restoration site, structures to protect downstream watercourses against the leached solids and nutrients should be constructed along their banks before ditch-blocking work starts.

7 Restoration work

Pekka Vesterinen, Maarit Similä, Sakari Rehell, Suvi Haapalehto and Rauli Perkiö

The most commonly applied peatland restoration measure involves blocking and damming drainage ditches with an excavator. It is often also necessary to fell and remove trees in naturally open or sparsely wooded peatlands and along the banks of the ditches to be blocked.

7.1 Clearing trees along drainage ditches

If dense tree cover grows alongside ditches and the spoil excavated from the ditches is consolidated by tree roots it may be necessary to clear trees mechanically or manually using a motor saw or a brush saw (Figure 27). If the cleared trees are not removed they should be felled to fall away from the ditch so that they will not obstruct the work of the excavator. Care should be taken not to leave too many trees in a ditch to be infilled where they could together form a kind of sub-surface drain inside the infilled ditch.

7.2 Removing trees

It is often necessary to remove tree stands in sites where drainage has led to considerable increases in tree cover in naturally open or sparsely wooded peatlands (Figure 28). Removing tree cover

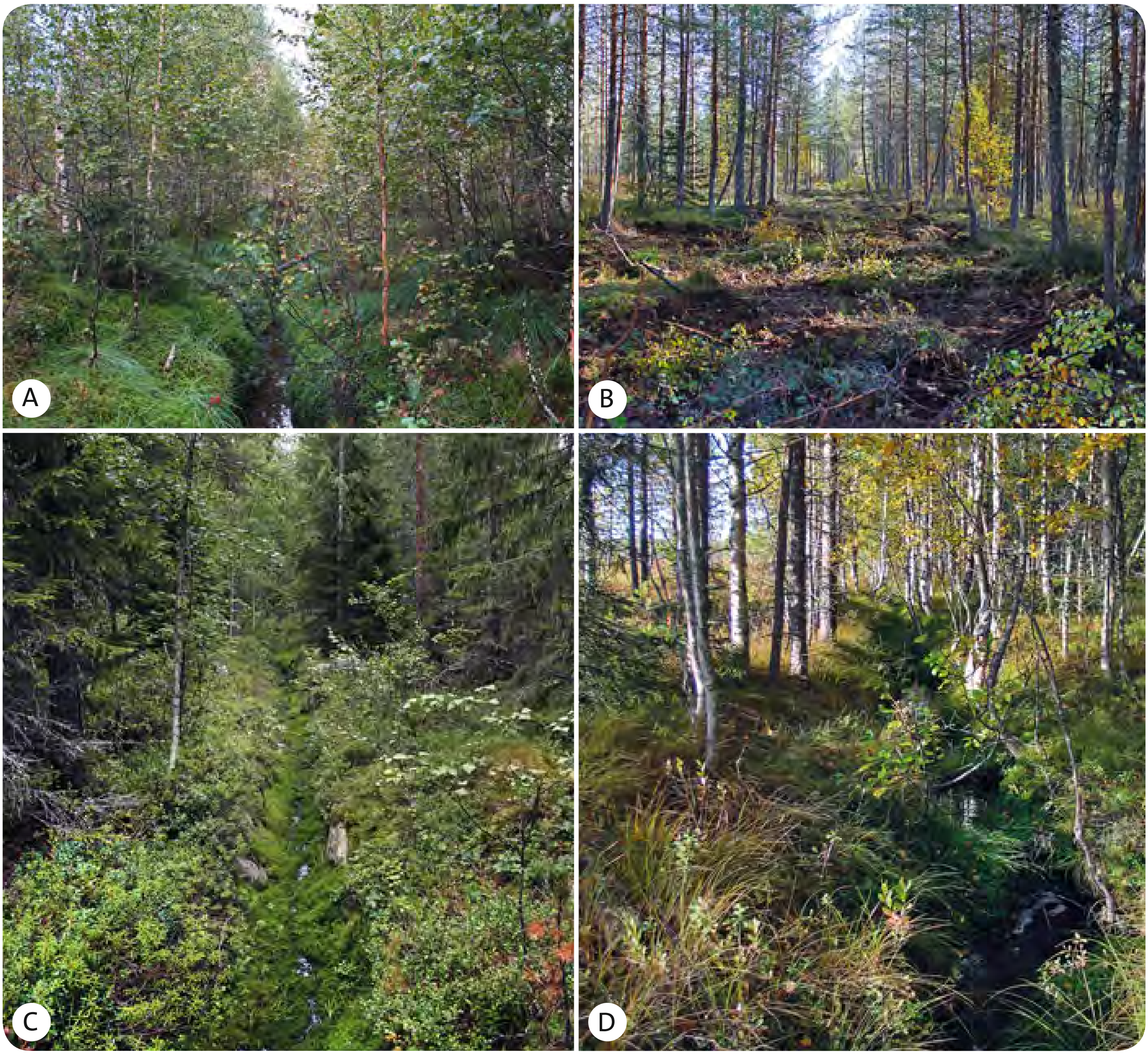


Figure 27. *Even where small trees grow densely (A) this should not normally hinder mechanical infilling. Photo B shows a stretch of the same ditch after restoration where trees were not cleared alongside the ditch. Clearing is usually not needed along ditches by which only a few larger trees grow (C); though trees thicker than a man's arm that consolidate the spoil excavated from a ditch often need to be cleared (D).* PHOTOS: SUVI HAAPALEHTO (A, B, D) AND MAARIT SIMILÄ (C).

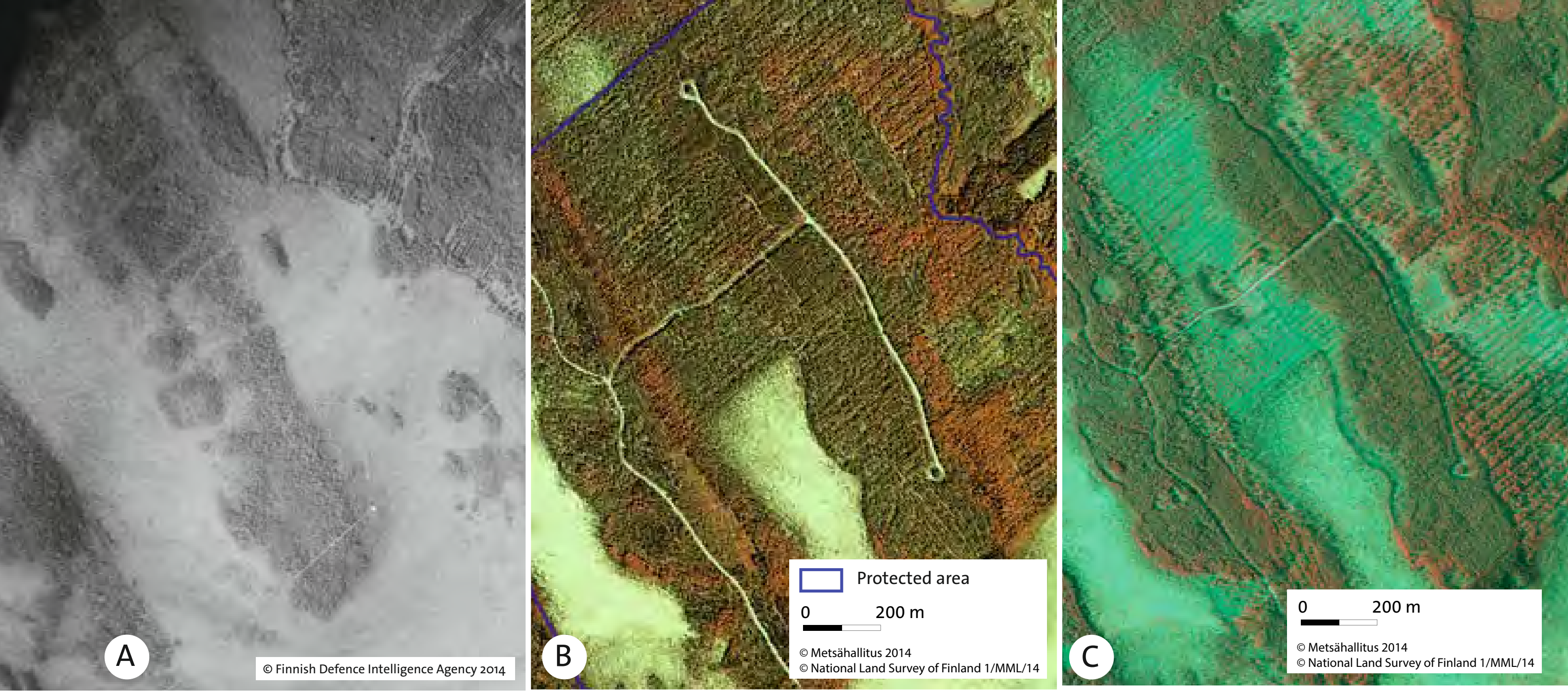


Figure 28. *During the restoration of the aapa mire Ringinsuo in Pieksämäki workers removed more than 10,000 m³ of pine that had grown in an area of 55 hectares since the peatland was drained. The old aerial photograph A is from 1938; photo B was taken prior to restoration in 2006; and photo C shows the site in 2011 after restoration.*

reduces evapotranspiration, restores more natural light conditions, and otherwise helps the landscape to revert to a near natural state more rapidly.

Old aerial photographs can be useful when estimating how many trees need to be removed (Figure 28), though when examining photographs it should be remembered that trees were often felled on peatlands prior to their drainage.

Trees are usually removed mechanically from a peatland site to be restored (Figure 29) before ditches are blocked, since at this stage the site conditions are drier than they will be later. Mechanised tree harvesting requires solid ground, and is usually only possible in winter when the surface of the peatland is frozen. Lighter forestry machines fitted with caterpillar tracks suitable for peatland conditions are most commonly used.

It is not always worth using forestry machines when restoring originally open peatlands, if there are so few trees that leaving them in place will not have significant negative ecological impacts, or if it is difficult to get machines onto the site (e.g. if the site lies beyond an extensive natural peatland or a natural stream). Trees will often die off in any case as water levels rise.

In small sites where relatively little felling is required or in sites requiring special care, trees may be felled and removed manually, though manual work is typically more costly than mechanical options (Section 7.7). Even in sites were manual labour is used it is usually necessary to use a forest tractor or a forestry machine with caterpillar tracks to shift timber to a roadside storage point.

Especially in originally open drained peatlands that are more nutrient-rich or have been fertilised, the dominant tree species is often white birch. When birches are felled, thickets of brushwood saplings may grow prolifically from their stumps after ditches are blocked if the peatland does not become very wet after restoration. In summer birches have high evapotranspiration rates, so any birch stands left in a restored site or new birch brushwood thickets may slow reversion to more natural hydrological conditions. A case-by-case decision should be made on whether to leave in place any birches that have grown since drainage, allowing them to die gradually as water levels rise, or whether to fell them and risk thicket formation. It has been noted that with larger birches (diameter at breast height > 20 cm) there is a lower risk of thicket formation after careful ring-barking than after felling.

Figure 29. *This multi-purpose forestry machine is starting to remove trees from a peatland site that would naturally be open. It has also piled up logging residues including branches, which in this case will also be removed from the site.* PHOTO: PEKKA VESTERINEN.

Logging residues and energy wood

Decisions on the need to collect and remove logging residues such as branches and small-diameter trees from restored peatlands should primarily be based on the ecological objectives of restoration. In areas widely used for recreation it may also be necessary to clear away such residues for aesthetic reasons.

If large quantities of saleable timber are to be harvested in a restored peatland site (> 100 m^3/ha) it is usually also worth harvesting the crowns and branches of these trees as energy wood, since any logging residues left in the peatland will contain surplus nutrients. Rich fen species that thrive where levels of the main nutrients nitrogen and phosphorus are low may particularly suffer in competition with more generalist species if logging residues are left behind to release large quantities of nitrogen and phosphorus.

The most cost-effective way to fell and pile up small-diameter trees is to use a forestry machine or excavator fitted with a felling head or slashing device designed for harvesting energy wood.

7.3 Restoring hydrological conditions

To restore near natural hydrological conditions in a peatland site it is necessary to ensure that it receives all the natural inflows of water from its catchment area. Restoration must involve raising water levels in the peatland, slowing water flows, and diverting water to make it flow in more natural directions. It is worth informing excavator drivers about the overall objectives of the peatland restoration project in addition to the specific measures needed, e.g. informing them about how water currently flows through the site, and about the flows that should occur after restoration. This will help drivers to optimally utilise their professional skills and expertise towards the agreed hydrological restoration goals.

7.3.1 Infilling and damming ditches and diverting water

Hydrological conditions are most cost-effectively restored by infilling and damming ditches with an excavator (Figure 30). The peat used to dam or infill ditches can largely be obtained from the masses of ditch spoil material earlier excavated when the ditches were dug, but it is almost always necessary to also use additional peat from other suitable parts of the site. It is important not to dig up peat in a continuous mass along a line parallel to the ditch to be infilled, since this would in effect create a new ditch. If there is not sufficient peat for infilling the whole ditch, it is better to fill in some parts fully and leave unfilled gaps than to fill the whole length of the ditch incompletely.

The material used to infill ditches should be carefully compressed from the ditch bottom to the surface. At sufficiently short intervals peat should be formed into dams to ensure that water rises to the desired level after restoration. The peat alongside ditches has often sunk to levels lower than the surface of the peatland between ditches. The depth of this sinkage and the width of the sunken margin on either side of the ditch will vary depending on the characteristics of the peatland and other local conditions. Because of this sinkage

Figure 30. *(A) The excavator driver filled in this ditch by driving up and down its entire length. On the outward journey he filled in the ditch compactly (B); and on the return journey he completed the peat embankments and channels for water (C). Trees had been felled in this naturally open peatland site during the previous winter.* PHOTOS: PHILIPPE FAYT.

dams should be extended outwards with peat embankments to prevent flows along the course of the infilled ditch, and instead divert water away from it (Figure 31).

Peat embankments should be 1–2 metres long in the direction of the ditch and at least half a metre higher than the surface of the infilled ditch. To function effectively they should be densely packed and extend far enough away from the ditch – as far as the surface is depressed alongside the ditch line. A length of 5–10 metres is usually enough, though in some cases embankments need to be tens of metres long (Section 11.4). It is important to measure the depth of the depression of the peat where necessary to estimate a suitable height and length for the dams to be created (Section 6.3). The distances between peat embankments depend on the gradient of the peatland surface: the steeper the gradient, the more closely the embankments will need to be spaced (Figure 32). In typical sites intervals of 20–50 metres suffice.

Even after infilling the courses of ditches normally lie slightly below the level of the rest of the peatland, so water will still tend to gather there. During wet periods water flows can easily develop along the lines of former ditches if no dams or embankments have been built to block and divert the water. To reduce the pressure of accumulated water on dams and embankments, especially during flood seasons, water can be channelled onto the surrounding peatland, for instance by making the embankments using peat excavated from the lower side with regard to the gradient of the site. A shallow channel will consequently form above the embankment, diverting water more easily onto the peatland (Figure 33). Such channelling features are especially needed for interceptor ditches and other ditches with higher flow rates where the risk of water continuing to flow along the course of the infilled ditch is great.

Particularly in aapa mires it is important to ensure that surface runoff from adjoining areas with mineral soil can flow along its natural routes over any ditches dug on the boundary between the mire and the adjoining mineral soils. Where necessary such ditches should be infilled so that the surface slopes towards the centre of the mire.

Shaded relief images created using laser scanning data or levelling can be utilised if needed to address other hydrological issues, such as the optimal location along a ditch where blocking work should be started to avoid the danger of waterlogging nearby forestry land.

Dams and embankments should finally be covered with a layer of sphagnum moss peeled away from the surrounding peatland, to encourage suitable vegetation to take over rapidly. Vegetation helps to keep dams and embankments in place, reducing the risk that they will be washed away by floods. Using vegetation to cover infilled ditches near hiking routes also improves a site's landscape value. In wooded peatlands infilled ditches can also be landscaped by felling trees onto the line of the ditch. This also creates decaying wood, benefiting many species.

Peatland sites designated for restoration may have wet and boggy areas where excavators cannot work. Leaving occasional stretches of ditches unblocked in such wet locations does not usually lead to major problems from the restoration perspective. However, it may be necessary to consider alternative methods where leaving a ditch in a boggy location would have a significant impact on the hydrology of a peatland. It may be possible to dam the ditch in winter or make dams manually on a small scale.

If forestry machines removing trees from a peatland restoration site have left tracks where water accumulates and flows, such tracks should also be filled in when ditches are dammed and infilled.

Figure 31. *In this wet fen the courses of ditches remained below the level of the surrounding peatland even after infilling, so plenty of water still accumulated along the old ditch lines. As this had been anticipated, peat embankments were created at short intervals to spread the water more widely over the peatland. The direction of water flow is from right to left.* PHOTO: SARI KAARTINEN

Figure 32. *In wet sloping peatlands peat embankments are particularly important, since they help water to spread over the peatland rather than continuing to flow along the courses of infilled ditches.* PHOTO: ULLA AHOLA.

Figure 33. *It may be worth making very long peat embankments in key locations with regard to water flows. In this site embankments were about 60 metres long. The dimensions of the embankments were clearly marked in the field with ribbons to ensure that the excavator driver made them long enough. This photograph was taken from the site of the infilled ditch, where water earlier flowed from right to left. The embankment was made perpendicular to the ditch line. A channel formed where peat was dug up to make the embankment, and water now flows along this channel to feed areas of flark fen which had not been drained but had nevertheless dried out.* PHOTO: REIJO HOKKANEN.

7.3.2 Damming a ditch with no infilling

If no ditch-digging spoil is available, or if ditches are so sizeable and eroded that not enough material is available to infill them, hydrological conditions can be restored by damming ditches. In sites to be restored using machines dams can usually be made from peat dug from the peatland between the ditches (Figure 34). Dams must be big enough and compressed carefully to ensure they can withstand water pressure even during flood seasons. Dams should be at least two metres long in the direction of the ditch and at least half a metre higher than the surface of the peat alongside the ditch. Dams and embankments must also extend far enough onto the intervening peatland.

In certain special sites it may sometimes be possible to realise restoration by manually building a single dam or a small number of dams (Figure 37 and Section 11.2). This kind of smaller-scale manual restoration may be necessary in small, inaccessible sites or sites with sensitive species, for instance. Manually built dams usually need to be reinforced with geotextile and wood.

Dams need to be built at shorter intervals where the terrain slopes more or the peatland is very wet. They should be sited to take advantage of natural rises and depressions in the microtopography. When constructing dams it is worth noting that the water pressure is typically greatest in the lowermost dams in the restored area.

Special consideration should be given to the need to divert water onto the peatland behind dams (Figure 33). Water can be suitably diverted for instance by digging small feeder ditches of suitable depth and length leading onto the surrounding peatland from just upstream of the dams.

← ***Figure 34.*** *In the drained part of this raised bog the banks of spoil alongside this large ditch had decomposed completely. The peatland to the left of the ditch is undrained, and the drained peatland to the right of the ditch has been restored. An excavator working on the drained areas used peat dug up from the surrounding peatland to make dams and embankments. Dams were made at intervals of approx. 30 metres to high levels to ensure they would not be washed away during floods. The dams have functioned well and conditions in the bog are becoming more natural.* PHOTO: PEKKA VESTERINEN.

7.3.3 Special dams

In some cases, where unusually large amounts of water need to be dammed or re-channelled, when restoring steeply sloping peatland sites, or to prevent soil leaching, it may be necessary to construct dams reinforced with wooden supports and geotextile (Figures 35–39). This is best done by combining mechanical and manual methods. With such special dams it is also important to channel dammed up water in the desired direction, e.g. using feeder ditches, to ensure it does not flow over or around the dam, but instead onto the surrounding peatland or into the channel of a stream that is to be restored.

Figure 35. *Tongue-and-groove boards can be used to help make dams in large or badly eroded ditches. The geotextile used to cover the boards is only partly shown in these illustrations to enable their underlying structures to be seen. Illustrations: Tupu Vuorinen.*

Figure 36. *Log dams may be constructed where suitable logs can be cut from trees felled on the site. The top ends of the logs should stand out clearly above the level of the ditch banks. If the peat is deep, the logs can be sunk vertically into the peat, but where peat deposits are only shallow the logs can be put in place horizontally. The dam should then be covered with geotextile and peat. Log dams can be further stabilised with the help of supporting logs aligned at right angles to the other logs.* ILLUSTRATIONS: TUPU VUORINEN.

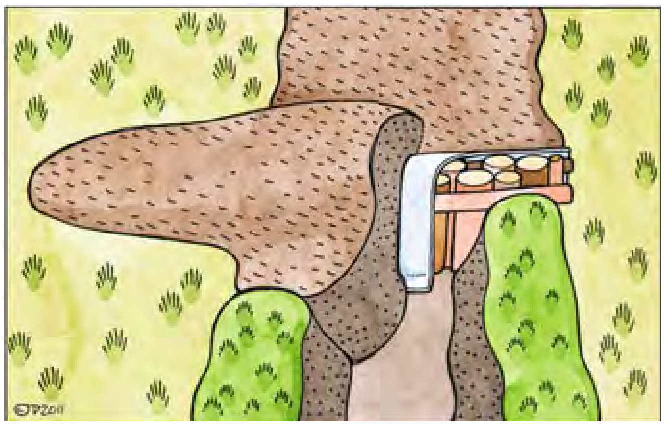


Figure 37. *Obliquely aligned log dams can be made by combining manual and mechanical work, though an excavator driver can often make a dam alone if suitable logs are available. The site for the dam is first excavated. It should be wider and deeper than the ditch for improved stability. Excavated peat and ditch spoil is then used to construct a diagonally profiled banked dam that rises above the level of the surrounding peatland. Log supports are then laid horizontally over the entire height of the banked dam. Geotextile can be laid down on top of or beneath the logs. In the illustrated example the direction of water flow is right to left. This kind of dam is suitable for almost all restoration sites in wooded peatlands.* ILLUSTRATION: TUPU VUORINEN.

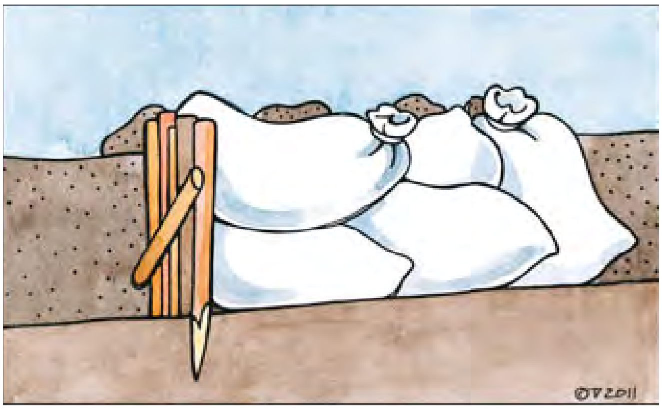


Figure 38. *Jute sacks filled with compressed peat can be put in place manually to dam ditches with sensitive springs or seepage areas, for instance. Such sack dams are also suitable for use when repairing dams in restored sites where excavators can no longer work. Sacks can be fixed in place using wooden stakes hammered into the peat.*
ILLUSTRATIONS: TUPU VUORINEN.

Figure 39. *Dams made of plywood can be used to block shallower ditches. Board should be sawn to sizes with greater length and depth than the ditch. To put them in place grooves can be cut in the peat using a long-reach motor-saw. The boards can then be hammered into place e.g. with a sledgehammer. Peat should then be shovelled in between the boards and packed tightly.* ILLUSTRATIONS: TUPU VUORINEN.

7.3.4 Small water features in peatland restoration

When choosing methods for the restoration of springs and seepage areas it is vital to ensure that the restoration work does not negatively affect any significant species present, e.g. due to excessive rises in water levels or changes in water quality (Sections 11.2 and 11.3).The methods used to restore peatland streams should be considered case-by-case. If drained areas have any stretches of natural stream bed that have dried out due to drainage, these natural features should be utilised during restoration by diverting water into them using suitably scaled and sited dams when drainage ditches are blocked (Section 11.6). Where necessary, the initial parts of such old channels may be cleared out to help the water find and follow its earlier natural course.

7.4 Increasing the abundance of decaying wood

Decaying wood is an important natural feature of all wooded habitats in the boreal coniferous forest zone. More than 4,000 forest species found in Finland are directly or indirectly dependent on deadwood (Siitonen 2001). After wooded peatlands are restored some trees usually die off as a result of rising water levels. Dead fallen trees also become available where ditches are blocked, when excavators knock over trees on ditch banks and landscape the infilled ditch line.

When planning to restore spruce mires with low amounts of decaying wood, it is worth considering the manual ring-barking of standing spruces or the mechanical felling of some trees, since these measures will increase the availability of decaying wood and make the forest structure more natural. Trees knocked over by an excavator together with their roots most resemble trees that have died naturally (Similä & Junninen 2012). If flows of water through the spruce mire are abundant it is worth waiting for several years after restoration to see how tree stands are structurally affected by the rising water level before taking any active measures to increase the abundance of decaying wood. The widespread death of spruce trees may increase risks related to the spread of the spruce bark beetle (*Ips typographus*), especially in Southern Finland. Though cool, shady and low-lying spruce mires are not ideal habitat for this insect pest, this risk factor should be considered particularly when working in small protected areas or near the margins of larger protected areas where commercially utilised spruce stands grow nearby.

In pine mires and open peatlands fallen trees rapidly become overgrown with sphagnum moss, so the manual ring-barking of standing trees is a preferable way to create more decaying wood.

7.5 General notes on the use of excavators

In peatland restoration sites the risk that a vehicle could sink into the peaty ground is often very high. Some of the boggiest parts of a site can be identified during the planning stage so that workers can be duly informed during on-site supervision. In practice the risks should be considered for the entire time a machine is working on a peatland site. In soft areas the surface peat may bear the weight of an excavator even though deep layers of watery peat lie beneath. It may be possible to improve load-bearing capacity by felling trees on site so that they lie beneath the vehicle's tracks. But the load-bearing capacity of surface peat is usually lost immediately if the vehicle turns so sharply that the surface peat layer is broken.

It is generally best to commence mechanical work in the higher-lying part of a catchment area, since it helps if water flows away from the machine. Where ditches lead directly into a watercourse structures should be put in place at their mouths where possible to protect downstream water bodies against excessive loads of suspended solids and nutrients (Section 6.4). Ditches carrying large quantities of water should be left until last. If heavy rain falls during restoration work, ditch flow rates may change rapidly.

To protect peatland birds and other animals during the breeding season, the most favourable time to start mechanical restoration work in Finland is early autumn, from August onwards. At this time peatlands are usually at their driest before autumn rains, which also makes it a favourable time to work. In special cases, such as very wet peatland sites, ditches may have to be infilled or dammed during the winter when the surface is frozen.

Anyone working near a machine should wear high-visibility clothing and a helmet. Special attention should be given to safety issues when building dams through a combination of manual and mechanical work. No one should ever work or walk beneath an excavator's bucket. Dam structures requiring pre-assembly should be constructed well away from the danger zone around a vehicle, and then lifted assembled into the ditch using safe and reliable equipment. Wherever possible dams should be designed so they can be assembled by the excavator operator alone.

7.6 Corrective measures

Even where restoration measures have been carefully planned and implemented, corrective measures may subsequently be needed. It is hard to predict soon after restoration work is completed where such actions may be necessary, so restored sites must be monitored in situ subsequently during dry and wet periods.

Since each peatland has its own distinctive features, deficiencies in a site's reversion to a more natural state may become evident in many different ways over larger or smaller areas. It may be necessary to postpone corrective measures for several years, where for instance an excavator needs to be used but water levels have risen so much that this would only be possible during a dry summer. In most cases corrective measures are not normally so urgently required, and a delay of a few years for observing the situation and waiting for suitable conditions can be acceptable. In nutrient-rich peatlands and sites where threatened plant species grow, however, corrective measures may be needed quite urgently. In such cases they may need to be realised using manual methods.

If lawns and flarks are observed as remaining dry during a normal summer, outside any periodic flooding, this indicates that water is still somewhere flowing too easily and rapidly away from the peatland, or that attempts to channel in the runoff that would naturally recharge the peatland from its catchment area have not been successful (Section 3.1). Infilled ditches may often still remain below the level of the surrounding peatland where the ditch lines have subsided and their spoil banks have been eroded. Dams may have originally been built too low or too narrow, or unexpectedly forceful flooding may have swept material away from the dams. If water is observed still flowing along an infilled ditch line, possible corrective measures include raising the height of dams and embankments. In aapa mires and other minerotrophic peatlands it is vital to ensure that incoming water can pass over any interceptor ditches earlier dug on the boundary between the peatland and neighbouring areas with mineral soils, since the hydrology of aapa mires means that they naturally receive runoff from such areas.

In sites where peat has subsided greatly following drainage, floods may occur after restoration. This does not necessarily mean that water levels have risen excessively, however. Flooding may in fact be a natural part of the process, and a good indication that dams have been built to sufficient heights and widths. But where excessive areas are left more permanently underwater it may be necessary to reduce the heights of some dams. This should not be done, however, if the higher-lying parts of a peatland are dry and water is only observed accumulating behind dams in the lower-lying parts. In such cases the heights of the dams in the upper part of the peatland need to be raised and the channelling of water improved to ensure that all parts of the peatland retain water.

Where deciduous trees are felled on a restoration site and water levels subsequently rise insufficiently, thickets may sprout from the tree stumps. Pine seedlings may also grow more profusely than had been intended. Clearing trees often exacerbates the sprouting of broad-leaved saplings, but it may resolve problems with pine seedlings. The best way to proceed is to slow the spread of undesired seedlings by enhancing the restoration of hydrological conditions.

In sites with valuable species, such as spring-fed and nutrient-rich peatlands, it is important to examine the state of plant species indicative of water quality as part of monitoring work. If species indicative of nutrient-rich conditions are evidently declining, it is important to check whether water of unsuitable quality is flowing into the peatland, e.g. acidic water flowing in from ditches outside the site. The planning and targeting of corrective measures may require analyses of water chemistry. Where water quality problems are evident, steps should be taken to rectify the situation as quickly as possible.

7.7 Costs of peatland restoration measures

The costs of peatland restoration projects vary depending on the extent of the site to be restored, and also on the type of peatland involved.

The time an excavator needs to spend on a project is shaped by factors including the characteristics of the earlier drainage scheme, the availability of material for infilling ditches, the extent of tree growth along ditch banks, ditch depths, how ditches are filled, the number of dams needed, and the structural design chosen for dams. An excavator can infill a typical ditch at a rate of about 80–100 metres per hour.

On the basis of Metsähallitus Natural Heritage Services' experiences up to the end of 2012 the mechanical restoration of "typical" peatland sites costs some €0.5–1 per metre of drainage ditch. If many large dams need to be built in addition to ditch infilling, restoration costs rise to €1.5–2.5 per metre of infilled ditch. Restoring natural streams and other special features costs some €3.5–5 per metre (including both machine work and additional manual work).

The costs of tree-felling and the income obtainable for harvested timber depend on factors similar to those affecting logging in commercially managed forests: the number of trees to be felled, felling methods, average trunk diameter and the method used for transporting logs to the roadside pick-up point. In sites with many mature trees the costs of mechanical harvesting (including felling and transportation to roadside) is typically around €10–15/m^3. In sites with lower quantities of saleable timber and long distances for transportation to roadside mechanical harvesting costs may rise to more than €30/m^3. The costs of manual felling in peatland sites amount to some €60–150/m^3.

Table 2. *Costs of various peatland restoration measures.*

Measures	Cost range
Mechanised harvesting of saleable timber from a peatland (incl. felling and forest haulage to roadside)[a]	€11–20/m^3, average €14.23/m^3
Long-distance transportation of saleable timber to a mill[a]	€6–10/m^3, average €8.16/m^3
Energy wood harvesting (incl. forest haulage to roadside)[a]	€20–35/m^3 s.u.b.
Manual tree-felling (4–11 m^3/day)[b]	€25–63/m^3
Forest haulage to roadside of trees felled by foresters[b]	€4–14/m^3
Clearing of ditch lines by foresters (trees left on site)[b]	€0.5–1.5/m
Continuous infilling of ditches, pine bogs and other larger peatland sites[c]	€0.45–1.2/m
Continuous infilling of ditches, sites with several smaller spruce mires[c]	€0.75–2.5/m
Dams made of peat[d]	€15–25/dam
Dams reinforced with wood and geotextile (incl. materials and costs of forestry assistants 40 €/h)[d]	€80–140/dam

a 2010 and 2011, not incl. value added tax
b 2007–2008, 3 sites in an area run by Natural Heritage Services, S. Finland, in Saimaa.
c 2005–2009, 8 sites in an area run by Natural Heritage Services, S. Finland, in Saimaa.
d 2008–2009, 8 sites in an area run by Natural Heritage Services, S. Finland, in Saimaa.

Table 3. *Relative costs of planning, supervision, implementation and purchased services as average proportions of total restoration costs.*

Type of work	Planning[a], %	Supervision[a], %	Implementation of restoration work[b], %	Purchased services[c], %
Infilling of ditches (11 sites)	8	5	20	67
Damming of ditches (1 site)	12	7	5	76

a Realised by Metsähallitus, incl. wages, daily allowances, transport and material costs.
b Including forestry work and payments to other Metsähallitus staff except for planning and supervision.
c Including services purchased from external contractors, equipment hire etc.

8 Problematic restoration sites

Sakari Rehell, Maarit Similä and Suvi Haapalehto

8.1 Rich fens, spring fens and other nutrient-rich peatlands

When restoring nutrient-rich peatland biotopes like rich fens or spring fens it is often essential to prioritise the measures required with care. Such sites are among the most challenging to restore.

Especially in rich fens and spring-fed peatlands it is important to ensure that water with the right characteristics is diverted onto the right parts of the site. This is the most important factor affecting the recovery of the demanding species that thrive in such habitats. Water quality must particularly be considered if opportunities to restore natural hydrological conditions are limited for some reason, meaning that the hydrology of the restored peatland will inevitably differ significantly from the situation before drainage. This may apply when, for instance, water must be channelled into a peatland at a limited number of points, or when there is a risk that runoff from the restored area will flow into the groundwater discharge areas (springs and seepage areas) or recharge areas.

Water quality parameters easily measurable in the field include pH, conductivity and colour. These indicators are often sufficient to estimate the risks associated with alternative actions. It is most important not to channel acidic water from surface runoff into springs, seepage areas or spring-fed streams.

Measures may need to be staggered to prevent excessively rapid changes (Section 11.2). It is usually recommendable to initially infill as many ditches as possible in catchment areas upstream of rich fens or other nutrient-rich peatlands, and then leave an interval of a few years before continuing restoration work. This allows water released from the catchment area during this disturbance phase to continue to by-pass the nutrient-rich peatland in ditches. Restoration work can then continue when water quality in the higher-lying restored area has become stabilised.

8.2 Sloping peatlands

When restoring sloping peatland sites special attention should be paid to dams and the channelling of water. Even small sloping peatlands may be affected by large quantities of water flowing through. Often a single main drainage ditch or a few ditches may transport more water than the others, though all ditches may not seem to contain much water, since flow rates on sloping terrain are rapid. In the planning phase of restoration it is advisable to monitor water flows during a flood season or after rains to identify the true quantities of water flowing through the site and its main pathways.

Sloping peatlands usually only have shallow peat deposits. At important threshold points dams should be reinforced with geotextile, and also with wood where necessary (Section 7.3.3), to ensure that they are not washed away during flooding. When infilling and damming ditches it is important to ensure that enough earth and peat embankments are constructed to sufficient lengths. In steeply sloping ditches water flow rates may become so high that small streams may form within them eroding deeper channels that will hinder the restoration of more natural hydrological conditions. It is also important to ensure that the tracks left by excavators working by ditches do not become more permanent watercourses. They may be dammed if necessary.

If a peatland sites slopes downwards from its margins to the centre, as in stream-side spruce mires, interceptor ditches should be infilled so that the infilling material slopes down to the centre of the peatland, enabling surface water from surrounding areas with mineral soil to flow along its natural pathways over the former interceptor ditches.

Planning restoration becomes even more challenging where a sloping peatland is spring-fed or has rich fen characteristics (Section 11.3). In such cases great care must be taken to determine water quality and ensure that more nutrient-rich water flows along its natural pathways.

8.3 Special considerations for peatland restoration in areas with sandy soils

In areas where peat deposits overlie soils that are highly permeable to water, the formation and discharging of groundwater greatly affect the ecology of peatlands. In areas where groundwater accumulates, depressions tend to develop into shallow or seasonally variable peatlands or raised bogs, depending on the permeability of the underlying ground. In areas where groundwater is discharged, springs and spring fens may form, including spring-fed swampy fens and rich fens. Such habitats often provide growth sites for rare and threatened plant species.

Drainage ditches dug in peatlands with underlying sandy soils may have extensive and unpredictable impacts. Ditches dug deep enough to reach the permeable ground can lower the water table over such a wide area that peatland vegetation dependent on groundwater flows may be impacted hundreds of metres away from the ditches.

Restoration measures may also have unpredictably wide-ranging impacts, even when realised on a relatively small-scale. Waterlogging impacts can easily extend beyond the boundaries of a protected area, for instance. In other cases, however, water level changes in restored peatlands fed by groundwater may only occur slowly, so the water table may not return to its natural level until after several rainy years. In groundwater-fed sites it may also be necessary to consider the requirements of rare and threatened species during the planning and implementation of restoration measures.

In areas with sandy subsoil ditches can easily become eroded, especially main ditches and ditches fed by groundwater discharges. Sand transported by the water may be deposited in stretches of ditches where the water flow becomes weaker. This can even block ditches or streams downstream, or form sandy “deltas” by lakeshores or on the margins of peatlands (Figure 40).

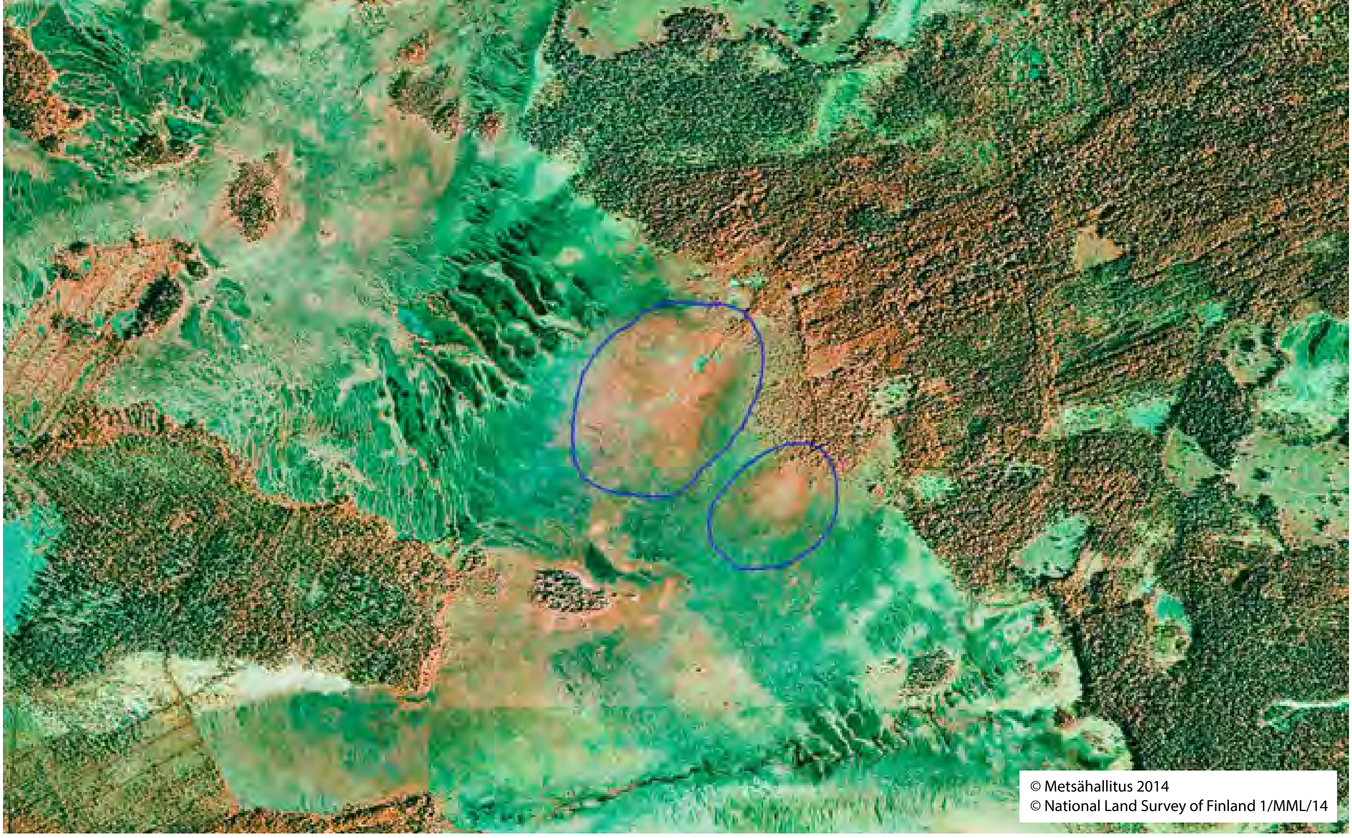


***Figure 40.** Sand transported in ditch-water from drained areas (top right) has accumulated in two delta-like features within this aapa mire (ringed). The image shows an area approximately 2 km wide.*

Suitable material for blocking eroded ditches in areas with sandy ground is not often readily available. It may be necessary to excavate infilling material from dredged ponds or channels, or even transport material in from further away. Since dams made of sandy material are easily eroded, the embankments alongside dams should be built high enough to eliminate the risk that water could flow over or around the dam in any situation. Water flowing in from higher parts of the catchment area should therefore be channelled into the peatland in locations where there is no risk of erosion. Areas with sandy soils typically do not have distinct streams, but instead water largely flows and filters naturally diffusively through the permeable ground. Sandy banks forming natural dams very often have lower depressions where floodwater can flow. The low points of these threshold features determine the heights to which dam embankments should be built.

8.4 Peatlands in groundwater areas

The drainage of shallow, seasonally variable peatlands in areas where groundwater reserves form can lead to problems with water quality. In the worst affected areas water rich in humus and nutrients infiltrates directly into the groundwater, easily leading to reduced water quality (e.g. increased concentrations of iron and nitrates). In the longer run the restoration of such peatlands is justifiable for the purposes of groundwater protection even before ecological factors are considered. When larger peatland sites in such locations are restored, humus and nutrient concentrations may temporarily rise in the water that recharges the groundwater, initially reducing water quality. For this reason in groundwater areas care should be taken not to restore excessively large areas of peatland at the same time. Load peaks caused by restoration can be reduced by commencing with the seasonally variable areas at the lower margin of the area, where the groundwater is recharged, and then only later restoring higher parts of the catchment area after vegetation conditions in the recharge area have stabilised, so as to enable the vegetation to reduce the leaching of humus and nutrients into the groundwater.

A more common problem is that peatlands on the margins of sandy areas with groundwater reserves have been drained, leading to the discharging of water into ditches, and a consequent lowering of the water table. Large amounts of groundwater may be discharged into deep ditches through peat layers. This discharged water sometimes makes the ditches even deeper, further accelerating groundwater discharges.

Where changes have occurred in groundwater areas, it is important to assess which measures are needed and identify crucial locations where dams must be built. There is usually not enough infilling material available alongside eroded ditches. If moraine deposits resistant to erosion are available locally, moraine earth can be used to infill ditches. If ditches are in easily eroded sand or peat, the best solution could be dams lined with geotextile and also fitted with tubes to enable water to flow through them, or some other kind of weir. Such dams should be built at short enough intervals to ensure that the difference in height between consecutive dams is not too great. The tubes used in such dams should be large enough to cope with the amounts of water present during seasonal flooding. It is also important to raise the bed of the ditch both above and below the dam using earth. The raised ditch beds should then be lined with protective geotextile to prevent erosion.

9 Considering cultural heritage

Pirjo Rautiainen and Henrik Jansson

9.1 Historic uses of peatlands over the ages

In Finland people have utilised peatlands and established traditions and beliefs about them for thousands of years. Peatlands have provided many resources for people to use to improve their lot. Fodder was collected in flood meadows and sedge fens, while wetlands and swamps attracted game animals and birds that in turn attracted human hunters. Finland's peatlands are still important hunting areas today. People also came to peatlands to pick berries, cut peat, and extract "bog iron". They also provided important open land routes from place to place. Signs of these earlier uses of peatlands can still be seen in and around Finland's peatlands today (Figure 41).

Peatlands have not always been peatlands; at some time in the past they may have been lakes or sea bays where peatland plants and peat gradually accumulated over time. This means it is also possible to find in their peat historic relics dating back to activities that occurred before the peatland formed.

***Figure 41.** Old sharpened poles, earlier used to dry peat for household use, still standing in Peiliössuo Bog in Jokioinen in 2009.* PHOTO: HELENA LUNDÉN.

9.2 Cultural relics found in peatlands

9.2.1 Items discovered inside peat

Organic material may remain preserved inside peat deposits for thousands of years due to their moist and anoxic conditions. Such finds are sometimes revealed when drainage ditches are dug. Relatively little archaeological research focusing on peatlands has been conducted in Finland, but some archaeological excavations have uncovered valuable material for study. Though significant finds are rare, the chance that a discovery could be made during peatland restoration should nevertheless be considered.

Boats and fishing equipment of various kinds are often found where peat is cut or ditches are dug in peatlands that had earlier been lakes or bays. One of the oldest fishing nets ever discovered, known as the Antrea Net, was found in a Finnish peatland. Human remains are even rarer finds than relic objects, but such finds are not unknown in Finland.

9.2.2 Peatland meadows and related man-made structures

In Finland fodder for livestock was collected from flood meadows and peatlands until as recently as the 1950s. Villages and farms would have their own patches of meadowland in productive peatlands, sometimes located considerable distances away. This practice was most widespread in the north.

To improve the growth of sedges, horsetails and grasses, people used to build dams or ditches to flood the peatland surface with water, reducing the growth of mosses, dwarf shrubs, scrub and trees. These man-made floods also spread fertile silt over the peatland meadows. The remains of old dams of this kind can still be seen along some peatland streams, and such ditches may also be visible too.

The fodder harvested from peatland meadows was dried on hay poles and hay racks (Figure 42). In most cases all that remains of hay poles is short stubs of wood protruding from the peaty ground, often in a circle. Barns were often built in peatland meadows to store the dried hay (Figure 43).

People used to travel long distances to peatland meadows, and sometimes stay overnight in shelters or cabins built on more solid ground near the meadow. Haymakers' initials, sometimes dated, can still be found carved into trees beside such meadows. It is difficult to identify old meadows by their vegetation. They are more often identifiable by the remains of man-made structures, or from historical records. Some valuable and productive moist meadows in Southern Finland were marked on local maps from the 17th century onwards.

Peatlands were also cleared to create fields through a process where the

***Figure 42.** This hay rack in a swampy sedge fen in Sodankylä was photographed in 1959. Today this area lies beneath the waters of the large Lokka Reservoir.* PHOTO: RAUNO RUUHIJÄRVI.

peatland was dried and evened out. The surface was then burned, and manure was then mixed with the resulting ash to make fertiliser (Myllys & Soini 2008). When harvests declined in such fields, the topsoil would be burnt again. In Eastern Finland this type of peatland farming closely resembled local slash-and-burn cultivation practices. Later farmers added mineral soil to the peaty soil in such sites. Such types of peatland farming involved drying the peatland with drainage ditches. Peatlands divided into farmable plots by ditches in this way may sometimes still be recognised as formerly farmed peatlands, though they may often only be identifiable through historical records or place names.

***Figure 43.** The remains of an old peatland meadow barn, Ranua, 2008.* PHOTO: PIRJO RAUTIAINEN.

9.2.3 Raw materials obtained from peatlands

In the beds of peatlands, in lakes and around the margins of springs, precipitated deposits of iron oxides known as "bog iron" may be found. Before industrial-scale mining began these deposits were a vital source of raw material for the production of iron. Such iron oxide deposits have been utilised since the Iron Age, but most extensively between the 1860s and the 1880s (Lappalainen 2008). Iron obtained from Finland's lakes and bogs was used as raw material in early industrial foundries and to make farming tools. More recent bog iron extraction sites may still be recognisable as depressions in the peatland terrain, and the activity is still remembered in place names referring to the presence of iron (Lappalainen 2008). Iron for local use would sometimes be refined in charcoal pits dug on hillsides near the source of the bog iron (Laaksonen 2008).

Sphagnum moss and poorly decomposed surface peat has been widely used as litter for domestic animals, in dry toilets and as insulation in the buildings. The extraction of peat for such purposes was extensively practised in some localities, where co-operatives were set up to organise the extraction, drying and cutting of the peat. Traces of barns or racks used to dry peat for such purposes may still be visible in and beside certain peatlands (Figure 44). The traces of peat extraction are still visible in many places as depressions with exceptional vegetation among deposits of sphagnum peat (Figure 45) or as the remains of old peat stacks standing higher than their surroundings. In the 19th century peat was also still used to fuel blast furnaces, steam engines and even locomotives (Lappalainen 2008).

Deposits of diatomite also used to be extracted from certain peatlands (Lappalainen 2008). This mineral is formed of accumulated remains of diatom algae deposited when the peatland was still a lake. Diatomite was used in a variety of products ranging from toothpaste to dynamite.

9.2.4 Travellers' routes through peatlands

As extensive relatively open areas peatlands were earlier widely used by travellers, especially during the winter when they were covered with ice and snow. No traces of winter travellers remain; but to facilitate travel at other times of year bridges, duckboard trails and log causeways were built to help travellers along well used routes. Duckboard trails most often consist of pairs of planks laid down lengthwise across stretches of boggy terrain. Log causeways were made of many logs or poles laid down across the pathway to facilitate horse-drawn transportation. Some of the duckboard trails maintained for hikers visiting protected peatland areas today still follow these much older routes.

9.2.5 Peatland folklore

According to Finnish folklore peatlands were bad places – bringers of frosts, the root of evil beyond the forests, and the end of everything (Tanskanen 2009). Mysterious will-o'-the-wisps were seen there, and Death himself was said to ski over the bogs. These beliefs have left no traces in peatland landscapes, but some of these old folk tales are still told. Since frosts were thought to originate in peatlands, they were widely cleared during the 1800s. Conversely people also used peatlands as refuges during times of war or persecution, as their persecutors were unwilling to venture there (Sepänmaa 1999).

9.3 Landscape values

Peatlands cover almost 30% of Finland's total land area. Attitudes towards them have traditionally been negative, since they have been seen as ugly, monotonous, unproductive and unwanted features (Kivelä 2006). However, they are an essential part of Finland's natural environment and scenery, even though Finland is more widely seen as a land of forests and lakes. There has been a widespread attitude that peatlands only gain any value after they have been drained and converted to farmland or used for peat extraction or timber production. But as more peatlands have been harnessed for these purposes, our appre-

***Figure 44.** Sphagnum moss sods cut for use as livestock litter left out to dry, 1982.* PHOTO: RAIMO HEIKKILÄ.

Figure 45. *Areas where peat was formerly cut still stand out clearly from their surroundings today.* PHOTO: HANNU NOUSIAINEN.

ciation of the value of the remaining natural peatlands has also grown (Kivelä 2006).

During restoration it is important to also consider the earlier uses of peatlands and their historical landscapes. Dams originally built to create peatland meadows or long abandoned peat pits, for instance, may today form essential elements of local landscapes. If traces of the historical uses of peatlands are discovered during restoration work, it is worth discussing possible management measures with cultural heritage specialists.

9.4 Considering cultural heritage sites

9.4.1 Investigate any known cultural heritage sites

When planning restoration measures it is important to find out whether there are any known cultural heritage sites in the areas that will be affected. Such sites may include legally protected archaeological sites, other sites of archaeological interest, and buildings of value as cultural heritage.

The old aerial photographs often used during the planning phase of peatland restoration projects are an excellent source of information on the locations of old buildings and structures such as meadow barns. Old maps may also give some insight into earlier uses of peatlands, though professional assistance may be needed when interpreting such sources.

Areas with mineral soil adjoining or isolated inside peatlands may well contain many kinds of cultural heritage sites from traces of prehistoric settlements to old hunters' pits and old military relics. Such features must be considered when planning access routes for the machines used in restoration.

Such areas may not appear ideal for settlement today, but in ancient times the landscape may have been quite different. Any isolated patches of higher-lying mineral soil inside a peatland may earlier have been islands within open water, used by fishers and seal-trappers.

Inventories of cultural heritage sites are never totally comprehensive, and in many peatland areas such surveys may never have been conducted. Even if an area has been inventoried previously unknown sites may still be discovered.

9.4.2 Implementing restoration measures near cultural heritage sites

The presence of ancient relics or other cultural heritage sites will not necessarily impede restoration work, and carefully planned measures can still be realised. The critical phases of restoration work should be identified, such as the movements of machines, any excavation of peat, and the storage of felled trees. Sites in the surroundings of the peatland should also be duly considered.

The most essential procedure is to ensure that information about the precise nature and location of any cultural heritage sites, and how they should be considered during restoration work, is passed on by planners to the personnel who will do the work in practice, including machine drivers and forestry workers. These personnel should also be aware of the kinds of cultural heritage sites that may yet be found in peatlands, and what they should do if they discover any previously unknown structures.

Trees felled in peatlands to be restored should be piled up and stored safe distances away from any cultural heritage sites to avoid any damage from log-piles or vehicles. It is usually worth felling trees growing in the immediate surroundings of structures such as old meadow barns, though it is worth checking first to see if any old haymakers' engravings remain visible on them. Trees should be carefully felled to award damaging structures. Logging residues should also be removed around such sites.

When digging any new ditches to channel water flows, or filling in old ditches using peat from other locations than ditch spoil, new discoveries of organic material preserved in peat are possible. If finds consist of objects such as wooden structures that are clearly man-made, or in rare cases even human remains, digging should be halted immediately and the museum authorities or other cultural heritage specialists should be contacted. Artefacts or other newly revealed objects should not be removed from the peat for inspection, since they could rapidly dry out and be destroyed without the protection provided by the moist, anoxic peat.

Cleared out streams may also sometimes be restored during peatland restoration work. In such cases it is important to ensure that streams do not contain the remains of old dams or log-floating flumes etc.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10 Monitoring the impacts of restoration

Figure 46. *A general monitoring visit to this peatland site, restored five years previously, reveals that a dam has functioned well.* PHOTO: MAARIT SIMILÄ.

Jouni Penttinen, Kaisu Aapala and Maarit Similä

It is essential to monitor the impacts of peatland restoration so that progress towards the objectives of restoration and the effectiveness of restoration measures can be evaluated. Finland has set up a national network for the monitoring of the impacts of peatland restoration on hydrology and biodiversity (Hyvärinen & Aapala 2009, Aapala et al. 2012). Every restored peatland should additionally be monitored in the field to determine the need for future management.

10.1 General monitoring

General monitoring aims to:

1. determine whether restoration has been technically successful
2. examine whether an ecological succession through which the peatland will revert to a more natural state has been triggered as intended
3. identify any problems in good time
4. improve restoration measures and the planning of future restoration projects on the basis of practical experiences.

During general monitoring visits surveyors should examine significant factors related to the reversion of the peatland to a more natural state, including the amounts of water feeding the peatland and how well such natural water flows have been restored, the effectiveness of ditch infilling and dams (Figure 46), and recovering or declining trends in the occurrence of peatland vegetation and other species. These observations should then be used as a basis for decisions on any further management measures that may be needed. General monitoring may reveal areas that have successfully reverted to more natural conditions, or other areas where the desired processes have not been effectively established, where corrective measures or further monitoring may therefore be needed.

The first post-restoration general monitoring visit should be scheduled for the first spring after restoration. If no problems are observed during this visit, general monitoring may next be scheduled for about ten years after restoration. Problematic sites may be monitored more frequently and over a longer period than 10 years.

10.2 Hydrological monitoring

Restoration primarily aims to re-establish peatlands' natural hydrology, and hydrological monitoring involves direct observations of such trends. Finland has a nationwide network of sites where hydrological monitoring is conducted in natural and restored peatlands in protected areas (Hyvärinen & Aapala 2009). Hydrological trends are monitored after restoration using devices that automatically measure water levels between May and September. The chemical properties of water samples collected three times during the snow-free season are also analysed (Figure 47).

The impacts of peatland restoration on watercourses downstream are monitored in Central Finland and Northern Ostrobothnia (Info box 4). The quantities of runoff discharged from restored peatlands are monitored using automatic data logging devices, and they are also regularly measured manually at selected weirs. Water quality parameters including pH and nutrient concentrations are monitored in runoff samples collected during the snow-free period.

10.3 Biodiversity monitoring

Biodiversity monitoring aims to identify any changes occurring in peatland species and their relative abundance after restoration. Some species are likely to return or become more abundant in restored habitat, while others may decline or vanish. It is difficult and costly to monitor entire species assemblages in peatland ecosystems, so a few species groups have been chosen to indicate indirectly the degree to which the whole ecosystem is recovering.

Vegetation, and especially the mosses of the ground layer, play a vital role in the functioning of peatland ecosystems and in efforts to restore their characteristic features. Permanent vegetation monitoring plots have been designated in peatlands to be restored in protected areas and in comparable natural peatlands (Hyvärinen & Aapala 2009). The vegetation data compiled from surveys of these plots after restoration is compared with data obtained from the same monitoring plots prior to restoration, and also with data from plots in comparable natural peatlands. The results of these comparisons indicate whether the desired changes in vegetation have been successfully triggered by the restoration measures, and how closely the resulting structures of vegetation communities at the time of monitoring resemble those in comparable peatlands in their natural state.

Restoration also affects peatland animal species and their population sizes. The impacts of restoration on peatland butterflies are studied in Finland with the help of a national monitoring network (Hyvärinen & Aapala 2009, Figure 48), and during the years 2010–2014 dragonflies and birds are also being monitored as part of the Boreal Peatland LIFE project (Metsähallitus 2013). Many species within the invertebrate taxa microlepidoptera, ants and spiders are also mainly or exclusively associated with peatland habitats; and if resources become available it would be worth expanding monitoring to cover such species. It would similarly be worth monitoring how the vegetation and benthic animal species and communities found in springs are affected by the restoration of peatlands.

Figure 47. *Data obtained by analysing water samples is used to assess hydrological changes following restoration, and how they differ between different types of peatland.* PHOTO: MAARIT SIMILÄ.

Figure 48. *Butterfly species can be surveyed in peatlands on warm, dry, calm summer days.* PHOTO: KARI-MATTI VUORI.

11 Peatland restoration case studies

Every peatland site requiring restoration has its own distinctive features. This section reviews illustrative examples of Finnish peatland restoration projects (Figure 49) that have been challenging in various ways.

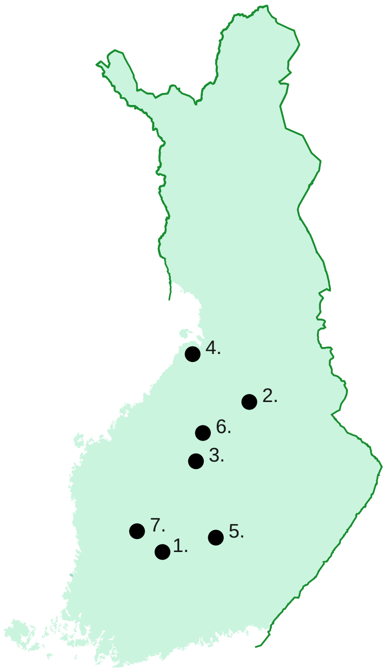


Figure 49. Locations of the case studies: Huppionvuori (1), Talaskangas (2), Kismanniemi (3), Revoneva (4), Haapasuo (5), Suurisuo (6), Seitseminen National Park (7).

11.1 Restoration of a rich fen: Huppionvuori, Orivesi

Tapani Sallantaus and Harri Vasander

The rich fen at Huppionvuori, about 30 km NE of the city of Tampere, is 1.3 hectares in extent (Figure 50), and has a power line passing over it. When drainage ditches were dug here in the 1960s, ditches draining the southern and southwest corners of the fen were dug further away than usual from the edge of the adjoining area with mineral soil, because of the power line. Since calcium-rich groundwater seeps into the fen, and trees growing beneath the power line have been cleared regularly, significant occurrences of mosses and vascular plants associated with rich fen habitats have survived in a small area.

Restoration work began in 1994 with the manual blocking of ditches and tree felling. Dams were not yet built in the ditch that skirts round the northern edge of the peatland, as it was considered that the restored area would fare well even alongside an area still left drained for forestry purposes.

The slope of the mire is limited except in areas with springs and seepage in the southwest corner, and the catchment area is large in relation to the extent of the fen itself (Figure 50). In the parts of the mire above intercepting ditches the positive impacts of restoration soon became evident (Figure 51). When ditches were dammed the spring water discharge effectively rewetted the dried out surfaces of the marginal fen, and the struggling fen vegetation recovered rapidly. For instance, only a few withered shoots of *Scorpidium scorpioides* had earlier been found, but the species soon proliferated over an area of ten square metres, accompanied by other species including *Scorpidium revolvens* and *Campylium stellatum*. Species associated with springs also thrived, while conversely species more associated with drier calcium-rich growth sites, such as the moss *Thuidium recognitum*, declined.

The landowner later agreed that the whole of the fen could be restored using manual methods. In the central drained parts of the site, vegetation was very sparse prior to restoration. Mosses had particularly declined due to the increasing amounts of leaf litter. During restoration fairly mature tree cover, mainly consisting of birches, was largely removed, though small trees and a few isolated birches were left standing. During the summer after trees were felled more dams were constructed, helping the main incoming channel in the NW part of the site (Figure 50) to start feeding water into the centre of the fen, which had earlier been encircled by ditches.

Vegetation communities reacted quickly to the increased availability of light and water. But unfortunately the manually constructed dams crumbled one by one, and the peatland dried out again. By 1999 a dense birch thicket was growing under the power line. It was then decided that the site should be restored again, using machines this time. An excavator was used to dam the ditches again in summer 1999. The birch thicket was also cleared.

The vegetation in the part of the site that had been surrounded by ditches,

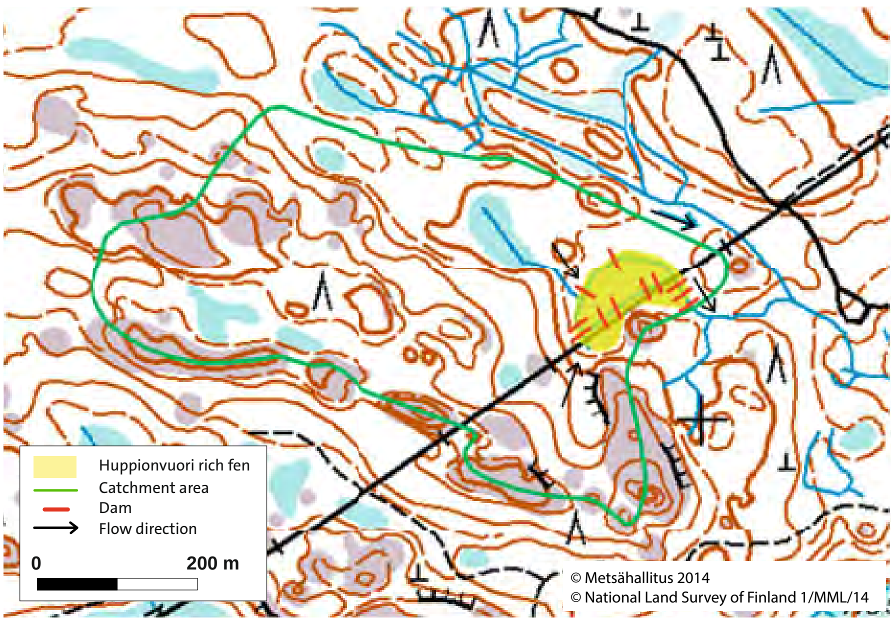


Figure 50. The rich fen at Huppionvuori with its catchment area. Incoming water flows and the points where most of the water will be discharged from the fen into a discharge channel are marked with arrows. Dams constructed in 1999 are marked by red lines.

Figure 51. *Carex flava and Trichophorum alpinum most clearly benefited from restoration in the margins of the fen that had not been so affected by drainage, which had also been kept open beneath the power line.*
PHOTO: TAPANI SALLANTAUS.

and therefore most radically altered by drainage, now consists of tall grasses, tall sedges and swampy spruce mire with sedges (Figure 52). Abundant species include *Lysimachia thyrsiflora*, *L. vulgaris*, *Viola palustris*, *Carex cespitosa*, *C. elongata*, *C. rostrata* and *Pedicularis palustris*. Thickets have been kept under control, and rising water levels have thinned out tree cover.

The moss species present are typical of swampy and herb-rich spruce mires: *Calliergon cordifolium*, *Calliergonella cuspidata*, *Helodium blandowii*, *Bryum pseudotriquetrum*, *Pseudobryum cinclidioides*, *Plagiomnium ellipticum*, *Warnstorfia exannulata*, *Sphagnum warnstorfii*, *S. centrale*, *S. squarrosum*. Notably, most of the moss species closely associated with rich fens (e.g. *Scorpidium* sp., *Campylium stellatum*) had not managed to spread over the dammed ditch, even though they were abundant on the far side of the ditch. This could be due to the acidification of the peat in the middle of the ditch as a consequence of prolonged drying out, or because of an increase in the amounts of soluble nutrients induced by restoration measures. Rich fen mosses cannot thrive in such conditions. Corresponding observations have been made in Holland, where due to high rates of atmospheric deposition of substances that accelerate eutrophication and acidification rich fen mosses have been replaced by the same species that have taken over the central parts of the rich fen at Huppionvuori (Kooijman 1992, 1993).

Concentrations of organic materials (TOC) in the runoff in the restored rich fen were still clearly higher than in natural rich fens or sites drained for forestry purposes even 12 years after restoration. This reduces the pH of the water and also leaches away reserves of calcium (table 4). Concentrations of nitrogen or phosphorus, conversely, were no longer higher. Total phosphorus concentrations were almost 100 µg/l in summer 2000, but by 2010–2011 they had fallen to below 20 µg/l.

The restoration can overall be said to have succeeded well. The type of peatland ecosystem now developing in the area most affected by drainage is not the same as the original site, or as rare, but it nevertheless represents a peatland type classified as threatened in Southern Finland (Raunio et al. 2008). Its plant species also include regionally rare species such as *Helodium blandowii* and *Amblystegium radicale*. Over time true rich fen species will expand their occurrences when the effects of the chemical changes induced by the drainage and restoration processes become weaker. The low availability of calcium may slow the process of reversion towards a more natural state. Rare and threatened rich fen mosses have spread successfully in many restored rich fens in northern sites which tend to be richer in calcium, and where in many cases the changes induced by drainage have not been as pronounced as in the rich fen at Huppionvuori.

Figure 52. *After restoration the most affected central parts of the site were taken over by grasses, herbaceous plants and sedges indicative of nutrient-rich and swampy conditions.*
PHOTO: TAPANI SALLANTAUS.

Table 4. *Average values for water quality parameters 2000–2011 measured in two sites for incoming water and in the discharge channel.*

	pH	alkalinity mmol/l	calcium mg/l	TOC mg/l	n
Incoming spring seepage	6.6	0.40	8.4	7	3
Incoming channel	6.3	0.27	7.6	13	5
Discharge channel	6.1	0.30	9.4	38	10

11.2 Manual restoration of springs: Talaskangas Nature Reserve

Sari Kaartinen and Sakari Rehell

Talaskangas Nature Reserve, some 45 km north of Iisalmi, consists of gently undulating moraine ridges interspersed with shallow depressions. The reserve is best known for protecting old-growth forests, but about half of its total area consists of aapa mires and wooded peatlands adjoining areas with mineral soils. Most of these peatlands are in their natural state, but drainage ditches had been dug extensively in some of their peripheral parts, which were restored between 2006 and 2008.

A moraine ridge known as Talaskangas, about four kilometres long and 700 metres wide, extends through the centre of the reserve. The groundwater that forms here is discharged in many small springs on the margins of the moraine ridge. The most significant area of springs lies to the southwest of the ridge, where as many as 13 distinct springs can be found in an area of spruce mire habitat (Figure 53). The spring-water has formed streamlets that flow southwest into a small river, though clear natural stream channels are not discernible.

In the 1960s and 1970s ditches were dug in the spruce mire and rocks were dynamited in places to facilitate water outflows. The new ditches cut through or passed by nine springs. Groundwater is discharged into the bottoms of these ditches. In many places moss species associated with mesotrophic springs have survived in small growths in ditch bottoms. The surrounding spruce mires have dried out, but their tree growth and the occurrence of deadwood remain representative. Three springs unaffected by drainage ditches are well preserved and still host moss species typical of open meso-eutrophic springs.

Ditches in the pine mires around the springs were infilled mechanically in 2008 (Figure 53), in some cases just a few metres away from the springs. The site was then left to recover undisturbed for a year, to see whether infilling the ditches nearest the springs would have any impact on them.

In autumn 2009 work began on the restoration of the hydrology of a few of the springs affected by the forest drainage, using manual methods and applying precautionary principles (Figure 53). Ditches above the springs were blocked with peat dams reinforced with wood, to block water that would not naturally flow into the springs. No measures were realised in the springs themselves. Weirs were instead constructed further away from the springs so that their natural spring pools could become re-established.

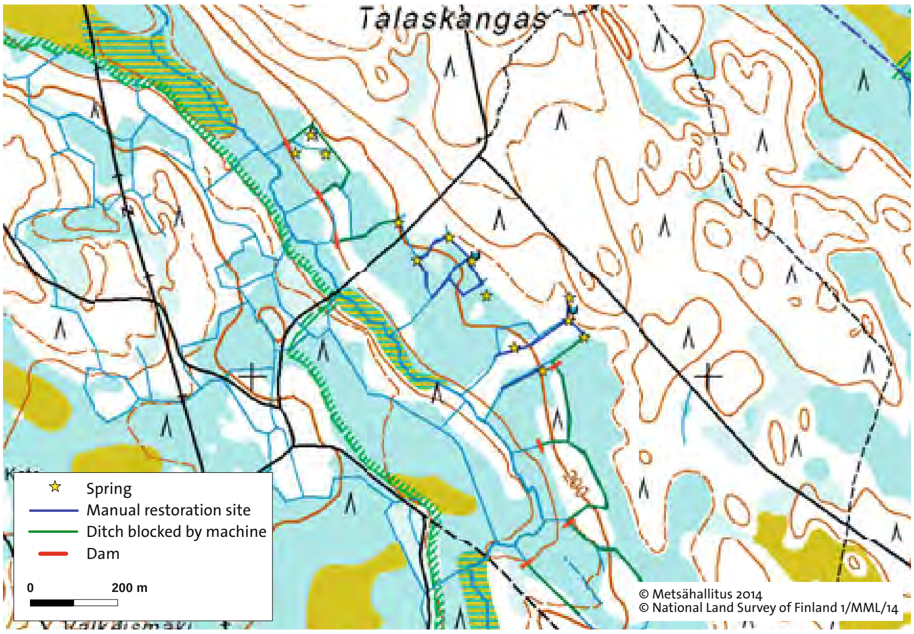


Figure 53. *Measures realised to restore the springs at Talaskangas. The boundary of the nature reserve is marked with a green shaded line.*

In 2010 water flow rates in the ditches slowed, and wider areas were affected by spring-water. Weirs made of stones, tree trunks and jute sacks filled with peat were built to raise water levels and spread the spring-water further. At the same time the ditches became more like natural streams (Figure 55). While the weirs were being constructed, mosses dependent on spring-water were lifted out of ditches to protect them (Figure 81). Stones earlier removed from ditches were rolled back into them, and the spring-water-dependent moss growths were transplanted onto stone or wood surfaces at a suitable height to enable them to continue growing. The aim was not to completely infill the ditch, but to carefully raise water levels in the surrounding spruce mires, and to make the channel where the groundwater now flows more natural (Figure 55).

A monitoring visit in 2012 indicated that restoration had been successful. The growths of moss species in the restored spring-fed ditches were sparse, but representative, containing species typical of nutrient-poor and acidic (pH 5.2–5.9) spring-water-influenced habitats in the region. The restored springs contained abundant growths of species including *Warnstorfia exannulata*, *Chiloscyphus polyanthos* and *Scapania undulata*. In some places near the springs old dried-out depressions could still be seen, indicating that the groundwater had not quite risen back to its natural pre-drainage levels, due to the precautionary approach adopted when planning the scope of restoration. The restoration measures had successfully promoted the re-establishment of springs, however, and the continued presence of preserved natural springs between ditches helped natural species to recover in the restored springs. The site will continue to be monitored with regard to the spread of spring mosses, and if necessary restoration work may later continue, with one option being to raise the heights of weirs.

The restoration work realised during 2009 and 2010 amounted to a total of 16 person days. Workers used motor-saws, spades, iron bars, jute sacks, a hand-operated winch and tie-down straps. Restoration work involved nine springs and the landscaping of ditches with a total length of about 650 metres. Planning and management work took up a total of four working days.

Figure 54. *The water level in this spring was raised with the help of a small weir built about two metres away. Spring mosses were lifted out of the stream onto a tarpaulin for protection during restoration work. The water level eventually rose by about 5 cm.* PHOTO: SARI KAARTINEN.

Figure 55. *Previously spring-fed water flowed deep in the ditch bottom and was hardly visible. Weirs were built to slow the flow and create pools of calmer water and small waterfalls. By calmer pools mosses can proliferate on stone and wood surfaces.* PHOTO: SARI KAARTINEN.

11.3 A spruce mire with many springs: Kismanniemi Recreational Forest, Kannonkoski

Reijo Hokkanen and Tuomas Haapalehto

Kismanniemi Recreational Forest, about 95 km NNW of Jyväskylä in Central Finland, is owned by the Finnish State. It is not a protected area, but its forests are managed with regard to their use for recreation and nature tourism.

A low-lying area of spruce mire habitat, about two kilometres long and 200–300 metres wide, lies around Koirapuro Brook, which drains the pond Koiralampi (Figure 56). The spruce mire has a total area of 25 ha which is today left to nature and not used for forestry. Its peat deposits are shallow, and the underlying ground is fine-grained. To the southwest of the spruce mire lies a parallel esker formation. One special feature of the area is the many springs that have formed on the slopes of the esker. The area has about 15 springs and seepage areas in all. The species found in these springs have suffered due to the drainage of the adjoining spruce mire.

Conditions pre-drainage and pre-restoration

From the vegetation present today it is evident that the upstream parts of the area (in the northwest) originally mainly consisted of fairly nutrient-rich and herb-rich spruce mire habitat. The high nutrient levels were due to abundant discharges of water from the springs bordering the esker that overlooks the mire (Figure 56). Flood waters in Koirapuro Brook have also probably spread nutrients over areas alongside the stream. Especially in the Koiraniitty area there are many seepage areas as well as open springs. The lower parts of the stream valley originally had more nutrient-poor spruce mire habitats

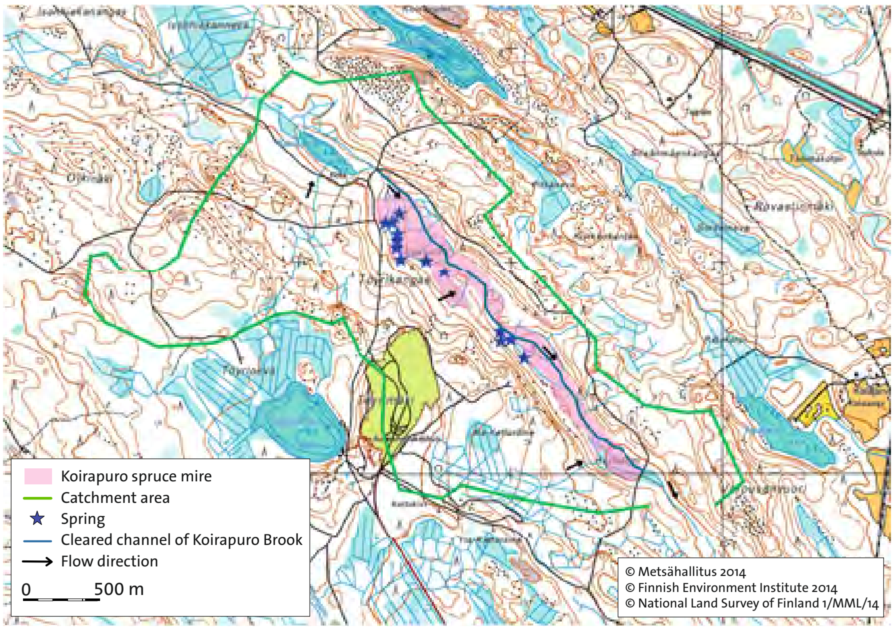


Figure 56. *Koirapuro spruce mire and its catchment area.*

dissected by a more nutrient-rich flood-influenced stream channel.

Drainage ditches were mechanically excavated in the whole of the spruce mire area in the 1970s. The area was also fertilised. Koirapuro Brook was also straightened during the drainage scheme, when a ditch was dug fairly directly along its course. Remnants of the original course of the stream were most visible at Koiraniitty. The old stream channel was about half a metre wide and 40 cm deep. Further downstream the course of the old channel could not be discerned in the field. Lateral ditches were badly eroded in places due to high flow rates and the fine-grained nature of the ground, especially around Koiraniitty. The largest ditches were 2 metres deep and wide. Ditches had been dug in connection with all of the springs in the spruce mire area. In many places ditches were dug directly through springs, lowering their water levels and preventing the spread of water onto the surrounding peatland by channelling it into the ditches (Figure 57). The springs consisted of roundish depressions approximately 1.5 m x 2 m. Groundwater could be seen gushing into the sandy bottoms of the most active springs.

Prior to restoration the vegetation in the spruce mire area consisted of herb-rich peatland forest type with bilberry (*Vaccinium myrtillus*). Its trees, mainly spruces, were 40–100 years old. Birches, pines and aspens were also present. In planted stands spruces and pines were growing very densely with hardly any undergrowth present, but elsewhere tree stands were still more natural-looking. Less than 5 m^3/ha of deadwood was present on average.

Mosses and vascular plants were surveyed in the spruce mire to help plan restoration. This indicated that the most important areas for plant species were the seepage area at Koiraniitty and areas alongside the stream flowing through the southern part of the area towards Hautakorpi. Common spring mosses were also observed in spring-fed drainage ditches. The same species were also present away from ditches in less extensive growths, especially in undrained seepage areas.

Restoration objectives

The main objectives defined for restoration were to re-establish near natural hydrological conditions in the spruce mire, and particularly to enhance conditions for species dependent on spring-water. This was to be done by redirecting flows of spring-water away from ditch bottoms and into more natural pathways. It was assumed that little could be done to directly improve the state of the springs. Their water levels had fallen due to the drainage ditches and erosion, but many of them were still discharging groundwater and providing habitat on a small scale for spring species, and it appeared that raising their water levels would probably not bring any additional benefit to the species present.

Another goal was to slow the water flow in the artificially straightened Koirapuro Brook to make it a more natural winding stream again. Unnaturally dense tree stands, mainly pine and spruce, were thinned out to increase the relative abundance of deciduous trees. The costs of the restoration measures were met using income from timber sales.

Considering the state of the worst eroded ditches it was assumed that restoration could potentially lead to the leaching of suspended solids into water bodies downstream, though it was also thought that water-filled basins in irregularly infilled ditches would serve as sedimentation ponds where solids would be deposited. The distance to the nearest significant recipient water body is several kilometres, reducing the risk of harmful excess loads.

During surveys the species present in ditches were also studied in detail, but no species were found that would have required ditches to be left unblocked. As a precautionary measure trees were not felled in the vicinity of the most important seepage areas.

Restoration

The area's tree stands were managed in winter 2009. Ditch lines were cleared and fellings were realised in 8 ha of planted forest stands to increase their structural diversity, mainly removing spruce and pine (about 500 m^3). Deciduous trees were spared and given more space by removing the surrounding spruces.

To protect the springs, and due to high water flows, the blocking of ditches was staggered over a two-year period. Springs and seepage areas were marked with ribbons so that the excavator driver would avoid them. In autumn 2009 a 3-km stretch of ditch in the northern part of the area was completely infilled using an excavator (Figure 58), with peat dams additionally constructed at intervals of 20–40 metres aiming to divert water onto the peatland. Larger and badly eroded ditches could not be totally infilled due to a shortage of ditch spoil, so they were instead dammed at

Figure 57. *Groundwater is discharged here into the middle of a ditch.* PHOTO: REIJO HOKKANEN 2007.

5-metre intervals with peat and earth dug up by the excavator. No wood or other reinforcing materials were used. In a couple of seepage areas water was channelled from springs into an old stream course by infilling ditches and removing ditch spoil that had been piled up blocking the entrance to the stream. At springs where no old stream courses had been evident, ditch infilling typically commenced about 10 metres downstream of the spring. Koirapuro Brook itself was not blocked, though a few spruces were felled into its course to slow water flows and provide growth substrate for plants. In a few places the stream water was redirected back into its earlier channel by piling up peat where necessary and clearing the entrance to the old channel.

During the restoration work Koirapuro Brook was crossed by the excavator only at a single point. The ditches in the southern part of Koirapuro spruce mire will be blocked in the near future.

After restoration

A year after restoration the area had become unevenly waterlogged, with the areas lying below springs most waterlogged. The largest pools in the infilled ditches below the springs were mainly a few square metres in extent. Due to the area's naturally sloping terrain, larger areas of open water had not formed. Water had successfully refilled older stream channels. One of the spring-fed streams had to be cleared out using a spade, however, to ensure that water levels in the spring did not rise too much. No major changes were observed in the springs themselves. Water levels had risen slightly in a couple of springs. Water had accumulated in the stretches of the site's larger, badly eroded ditches lying between the dams built to block them. Water was observed flowing over dams into the next water-filled Sections of the ditches, but no suspended solids were evidently being transported. In some places water was spreading away from the infilled ditches. Infilling the ditches unevenly had evidently helped to prevent the transportation of suspended solids, since water was only meandering slowly through the infilled ditches. Impatiens noli-tangere had clearly proliferated since the first summer due to the increased availability of light, having taken over areas of bare ground along ditches and where trees had been felled (Figure 59).

Nature made its own contribution to restoration work at Koirapuro spruce mire in July 2010, when a storm felled many trees, especially in areas where trees had already been thinned out. Ditch lines and other restored areas were subsequently covered by fallen trees. The largest such area was about 200 x 40 m in extent. The area's springs were not badly damaged.

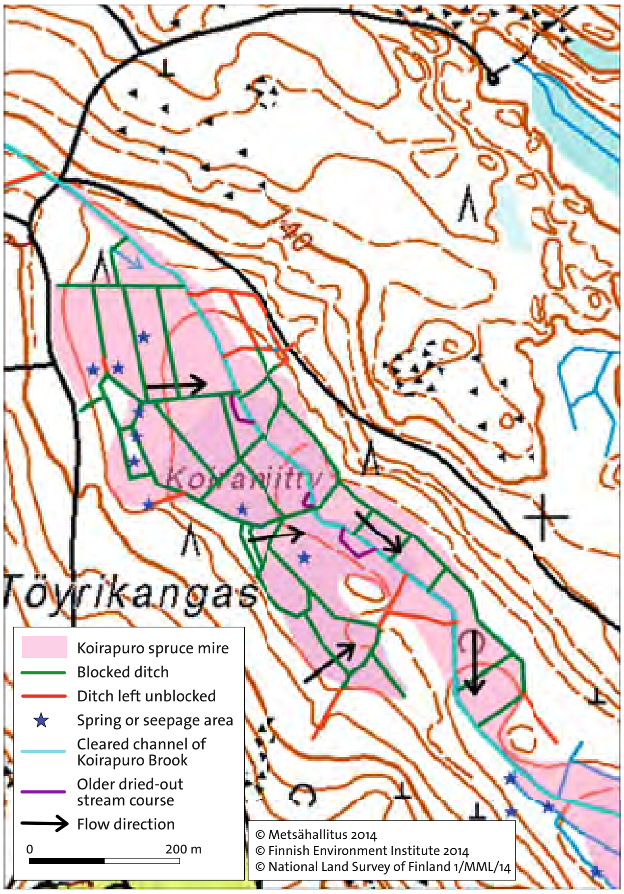


Figure 58. *Ditches in the northern part of Koirapuro spruce mire were blocked in 2009.*

Figure 59. *Impatiens noli-tangere took over ditch lines after restoration, and many trees fell during a storm in July 2010.* PHOTO: REIJO HOKKANEN.

11.4 Blocking the drainage channel of a wet, swampy aapa mire: Revonneva Nature Reserve, Siikajoki

Sakari Rehell

Revonneva Nature Reserve is in Northern Finland about 40 km SW of Oulu. *Sphagnum fuscum* bogs and aapa mires each account for about half of the reserve's total peatland area (Figure 60).

The eastern parts of the peatland's catchment area were largely drained in the 1960s. The water from these drained areas was diverted into a large drainage channel cutting through the wet aapa mire area and on to the River Siikajoki to the southwest.

This drainage channel also dried out large parts of the undrained aapa mire lying just west of the channel. As far as 500 metres west of the channel pine seedlings and dwarf birch were found growing in areas that had earlier been wet flark fen (Figure 61). The flarks had dried out, their vegetation had become more uniform, and the significance of the whole peatland area as a breeding and resting area for birds had declined.

When the peatland had been in its natural state water had drained naturally from a wide area into the central parts of the aapa mire (Figure 62), where the dominant peatland type was nutrient-rich, swampy flark fen. String structures were poorly developed, and peat deposits were more than two metres deep in places. It was calculated that the total area from which water had naturally flowed into the central parts of the aapa mire, but which was now drained via ditches into the main drainage channel, amounted to about 800 ha. The volumes of water flowing in the channel were consequently very high.

The drainage channel itself was 1–2 m wide and in many places extended into the underlying mineral soil. Its drying effect had led to severe subsidence in the surface peat alongside the channel (Figure 63), forming a much wider channel about 50 m wide. The surface of the peatland was levelled in autumn 2005 to determine the scale of the subsidence.

Because of the extensive subsidence alongside the channel, the restoration planners decided to construct sizeable peat embankments across the channel extending across the whole of the area affected by subsidence. Merely blocking the channel itself would have only led to partial success in restoration.

Revonneva Nature Reserve is almost totally surrounded by private lands. Negotiations with neighbouring landowners were held during the planning phase. A major information and discussion session was held, with landowners and the local authorities invited. Landowners were able to comment on alternative preliminary plans, and their comments were considered in the planning process.

Before restoration work commenced, the state authorities acquired an area of 10 ha of privately owned drained peatland that would be threatened by waterlogging (Figure 62).

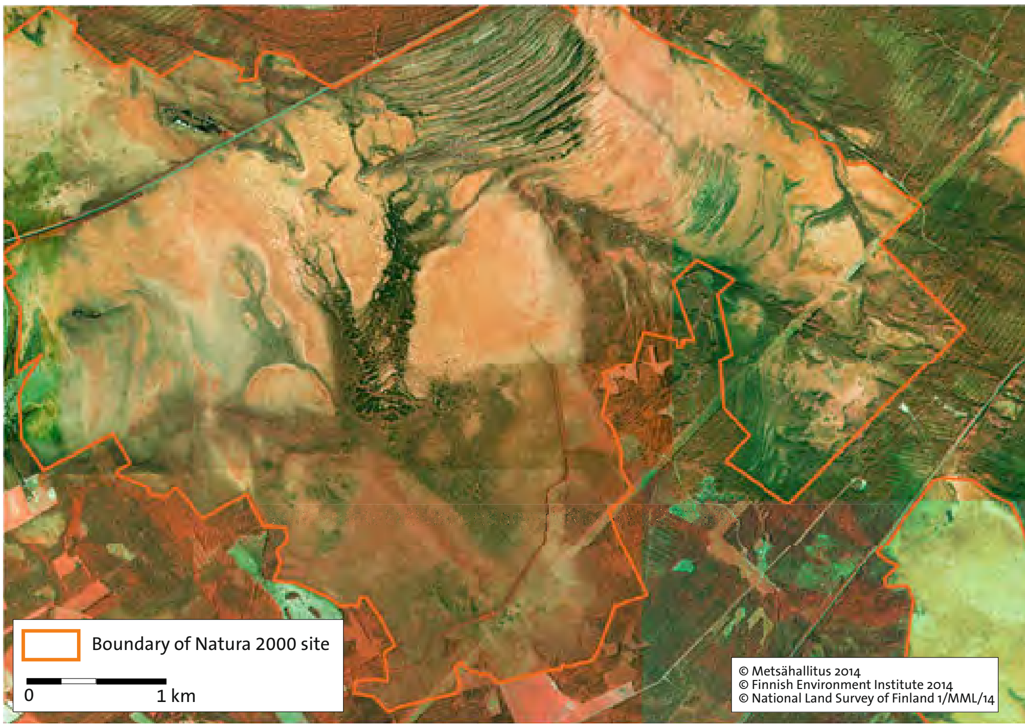


Figure 60. *Aerial photo of Revonneva before restoration. The drainage channel to be blocked is in the centre of this image.*

Figure 61. *Vegetation growing in a former flark fen which though undrained had been badly dried out by a drainage channel located about 200 metres to the east. Photo: Päivi Virnes, August 2006.*

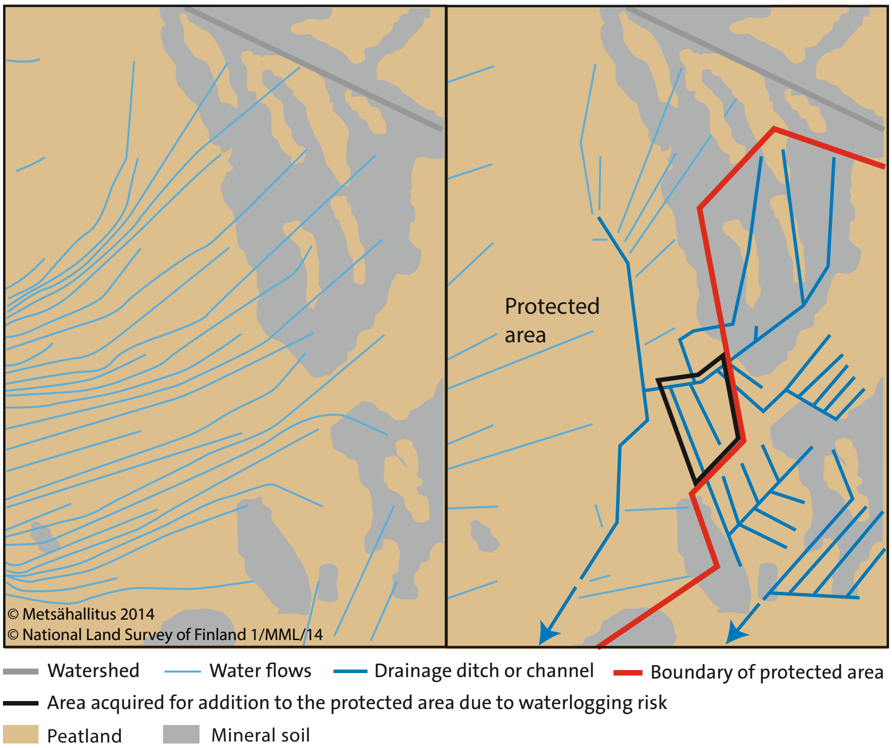


Figure 62. *Water flows at Revonneva before drainage (left) and after drainage (right).*

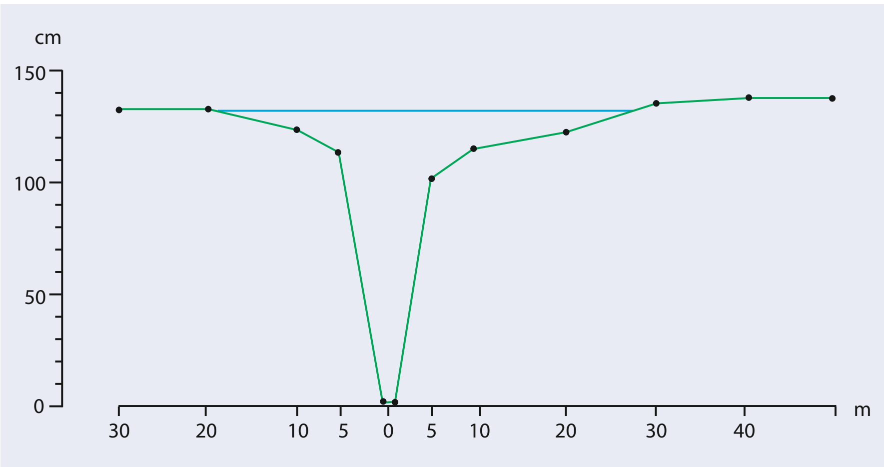


Figure 63. *Cross section of the drainage channel extending some 30 m west and 50 m east of the channel bed. Altitude zero marks the water level in the channel, which in this area was about 130 cm below the surface of the surrounding peatland. The blue line marks the level to which the water would have to rise for it to spread westwards towards the central parts of the peatland.*

Restoration

Restoration work began with the felling of trees in late winter 2006. Trees growing alongside ditches were felled for sale as energy wood. Along the main drainage channel a clearing almost 3 km long and 10–20 m wide was cut (Figure 64). A total of some 500 m^3 of energy wood was obtained from alongside the channel, and about 280 m^3 from smaller ditches. After the ditches were blocked, trees with a total volume of about 100 m^3 were manually thinned out between the cleared ditch lines.

In August 2007 the drainage channel was blocked by peat embankments about 50 m wide built at intervals of about 70 m (Figure 65). At the same time smaller feeder ditches were also blocked. To keep neighbouring private land dry some feeder ditches had to be left open and others had to be cleared.

The main channel was successfully dammed in spite of rainy conditions. The most difficult part of the task was starting work, since the channel was almost full of water. The first dams were built at the higher end. To get to the starting point at the top of the ditch the excavator had to construct a temporary "raft" of peat and roots for itself to avoid sinking. Immediately after the first dam was completed, water started to flow away from the channel towards the central parts of the open peatland, and the ditch started to dry up. This made damming the rest of the channel a lot easier. The final outcome was a 2.5-km-long chain of consecutive pools, and significant increases in the amounts of open water throughout the peatland. After the pools filled up, rising water levels started to affect the whole area west of the main channel.

Impacts of restoration

Two years after the drainage channel was blocked, water levels were observed to have risen throughout the earlier dried-out western half of the area to the extent that pine seedlings had withered or died due to waterlogging as far as 500 m from the former channel. No waterlogging damage was reported in neighbouring private lands, though the measures taken to avoid such problems reduced the impacts of restoration in parts of the margins of the protected area. Water was spreading onto the peatland in certain points from the ends of the ditches that had been left open, but elsewhere parts of the peatland were still dry. It was also necessary to leave a few hundred metres of the lower part of the main channel unblocked to prevent waterlogging in lower-lying drained fields. Consequently almost twenty hectares of the protected peatland area has not yet been restored. In future it is hoped that negotiations with landowners will result in solutions where natural hydrological conditions can be restored also in these areas, aided by additional measures including the clearing of field ditches and the construction of new culverts.

Following restoration the central parts of the peatland have been receiving about four-fifths of the water volume that they would naturally

Figure 64. *The scene in the cleared belt alongside the main drainage channel during the dry summer of 2006, before it was blocked.* PHOTO: PÄIVI VIRNES, AUGUST 2006.

Figure 65. *This peat embankment was constructed a couple of weeks before the photograph was taken. The pools excavated alongside have not yet filled with water.* PHOTO: PÄIVI VIRNES, AUGUST 2007.

receive. Near natural hydrological conditions have been restored in a total of some 200 ha of drained peatland (Figure 66). Within just two years the peatland plant species assemblages had quite rapidly reverted towards those of more natural flark fens.

Restoration costs

The project's excavator worked on damming and ditch-blocking for a total of about 11 days. Income from sales of energy wood covered less than half of the related felling and transportation costs.

The costs of restoration measures amounted to a total of approximately €17,500, of which about two-thirds consists of the net cost of fellings. The costs of excavator work were as expected, but the costs of felling trees rose well above the predicted levels.

The costs of restoration measures amounted to an estimated €800 per hectare of peatland where restoration measures were implemented. However, the measures realise at Revonneva will generate impacts over a total area almost ten times the extent of the area where measures were actually implemented, so costs per hectare in terms of the total area affected by restoration measures fall to some €90/ha. Planning and supervision costs have not been included in these calculations.

← ***Figure 66.*** *The view over the restored drainage channel looking west towards the centre of the open peatland, about a year after restoration measures were realised. The aapa mire is no longer drying out, and flarks are filled with water again.* PHOTO: SAKARI REHELL, JULY 2008.

11.5 Changes in vegetation and hydrology in an extensive gradually restored peatland complex: Haapasuo Bog, Leivonmäki National Park

Tuomas Haapalehto and
Tapani Sallantaus

The extensive Haapasuo Bog lies in Central Finland about 43 km SSE of Jyväskylä. The western part of this peatland complex is in Leivonmäki National Park, while its eastern parts have been used for peat extraction (Figure 67). Southern and eastern parts of the protected area of Haapasuo consist of aapa mires, while well-developed eccentric bogs are found in the north and west (Figure 68).

Changes induced by drainage ditches

Haapasuo Bog was drained in the 1960s. The ditch draining Lake Haapajärvi was dug in 1958–1960, lowering the water level in the lake by about one metre (Kärki 1990). Under earlier natural conditions no water channels had either fed or drained Lake Haapajärvi. Work on the drainage of all of the four areas marked on the map (Figure 67) began in 1962. The most recent ditches were dug in the 1970s in the eastern part of the area protected today. The area was acquired by the Finnish authorities in 1986 for the establishment of a nature reserve.

The drainage ditches have significantly affected the protected aapa mire Section of Haapasuo, leading to the drying out of peatlands, lower water levels in ponds, and considerably increased tree growth (compare Figures 68 and 69).

Restoration measures

Work on the restoration of Haapasuo Bog commenced in 1990, making it one of the first peatland habitat restoration sites in Finland. Ditches were blocked in four parts of the peatland complex using manual methods (Kärki 1990, Figure 67). In part of the area dams were mainly made of wood. In other areas peat dams were built at maximum intervals of 200 metres to levels 20 cm higher than the surrounding peatland (Kärki 1990). In the south some trees were also felled.

A survey carried out in autumn 1999 revealed that the peat dams and the wooden dams were still holding back water, but that the dams had been built at such widely spaced intervals that water had not risen onto the peatland (Suikki 2001). Banks of ditch spoil piled up alongside ditches had also prevented water from spreading onto the peatland, and not enough trees had been felled.

Further restoration work was then realised in different parts of Haapasuo during the years 2003–2008, when ditches were infilled with peat, and trees that had benefited from drainage were removed.

Changes in vegetation

In 1991, a year after the first ditches were dammed, a 24-square-metre vegetation sampling plot was set up in sub-area 4 of Haapasuo Bog for the purposes of monitoring subsequent changes (Seppä et al. 1993). Monitoring was then conducted 1, 10 and 15 years after damming. The most recent monitoring visit occurred a year after the further local restoration work involving the infilling of ditches had been realised.

Since no comparative surveys of changes in vegetation in a control area in its natural state were conducted, material from a study of ten comparable natural mires in Seitseminen National Park was used for the purposes of comparison (Haapalehto, unpublished, 2007).

The plant species observed at Haapasuo have shown signs of successful reversion towards plant communities associated with naturally wetter peatland habitats. The total cover of sphagnum mosses, the species most important for peat formation, increased during the monitoring period from 11% to 60%. However, this figure still remained below the typical sphagnum moss cover observed in natural peatlands (96%) (Haapalehto, unpublished, 2007). The moss species *Pleurozium schreberi*, which benefits from drainage but is almost absent in natural peatlands, had correspondingly not declined at Haapasuo following restoration. Another species that benefits from drainage, bilberry (*Vaccinium myrtillus*), had apparently gained ground rather than declining even 15 years after restoration (Figure 70).

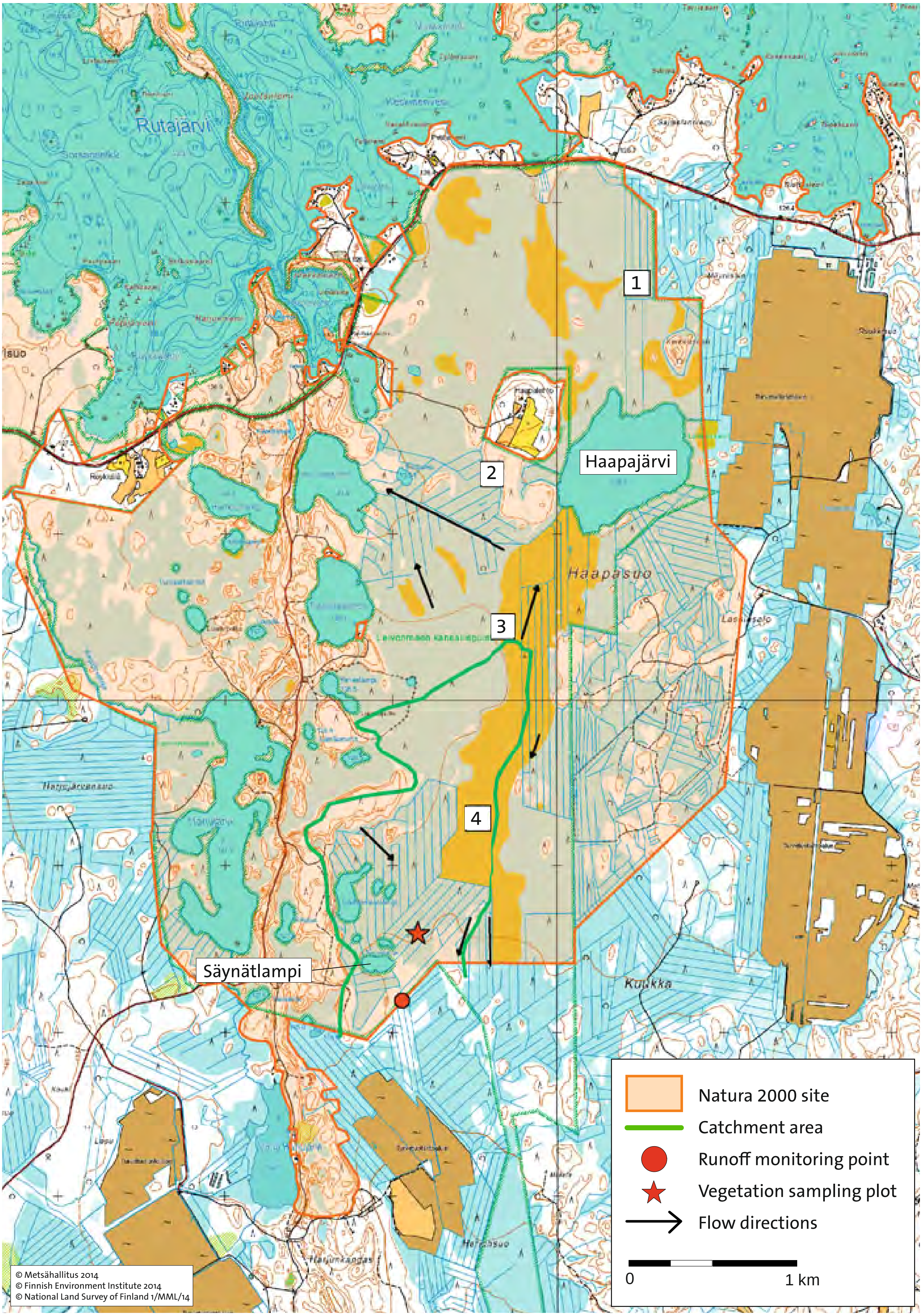
The limited changes observed in the plant species present at Haapasuo imply that to effectively restore natural vegetation communities it is necessary to implement more effective restoration methods than the damming of ditches alone, such as the infilling of ditches with peat combined with the construction of peat embankments to divert water away from the infilled ditch lines.

Qualitative changes in runoff water

Water quality parameters were monitored in runoff over the period 2002–2007 just downstream of the pond Säynätlampi (Figures 67–69). Flow rates at the measuring weir were recorded on each sampling visit. The natural catchment area of this water course is about 1.5 square kilometres in extent (Figures 67 and 68). About two-thirds of the catchment area consists of restored peatlands where ditches were initially dammed in 1990 and then infilled in 2004. Data is available on 33 water samples taken during the post-restoration period 2005–2007.

The hydrologic balance of Säynätlampi is unusual for a peatland pond. On the western edge of the catchment area is an esker formation consisting of well sorted and highly permeable glaciofluvial deposits, where an abundant reserve of groundwater forms. Even during the driest periods the outflow rate from Säynätlampi was more than 3 l/s, i.e. more than 0.2 mm/day for the catchment area, due to the number of springs in this area. Away from the esker, a considerable part of the catchment area consists of nutrient-poor peatland. During wetter spells the water is consequently acidic (with pH as low as 4.4) and brown in colour. Contrastingly

Figure 67. *Haapasuo Bog, Leivonmäki National Park. Peat extraction sites outside the national park are shown in light brown. The green line delineates a catchment area containing a runoff monitoring point. The northern boundary of this catchment area also forms part of a more major watershed that runs through Haapasuo Bog. The black arrows indicate natural flow directions, which also apply after restoration. The numbers relate to parts of the area drained or restored as specified in the text.* →



Rutajärvi
1
2
3
4
Haapajärvi
Haapasuo
Säynätlampi
Natura 2000 site
Catchment area
Runoff monitoring point
Vegetation sampling plot
Flow directions
0
1 km
© Metsähallitus 2014
© Finnish Environment Institute 2014
© National Land Survey of Finland 1/MML/14

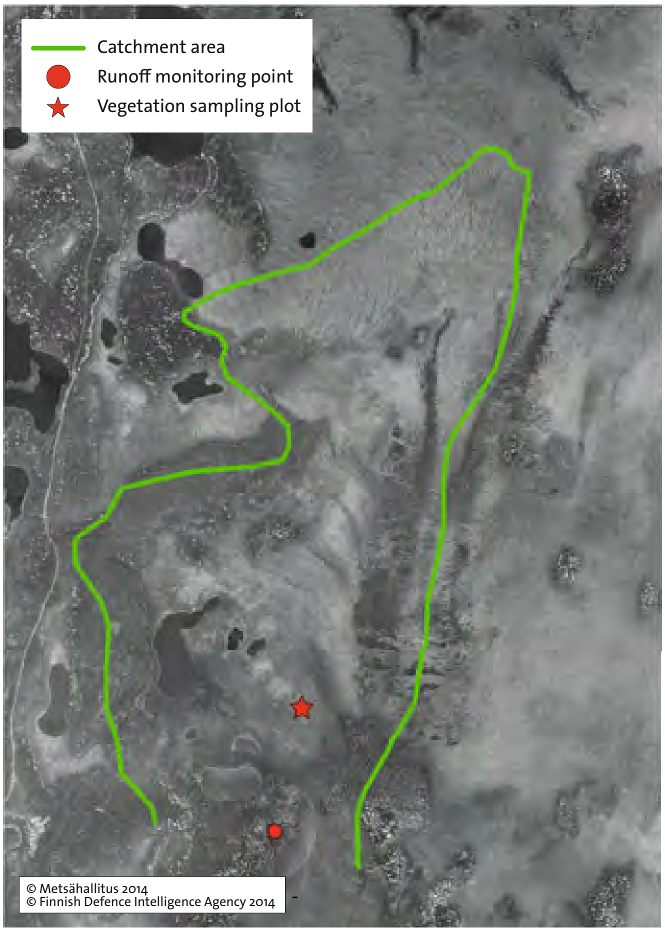
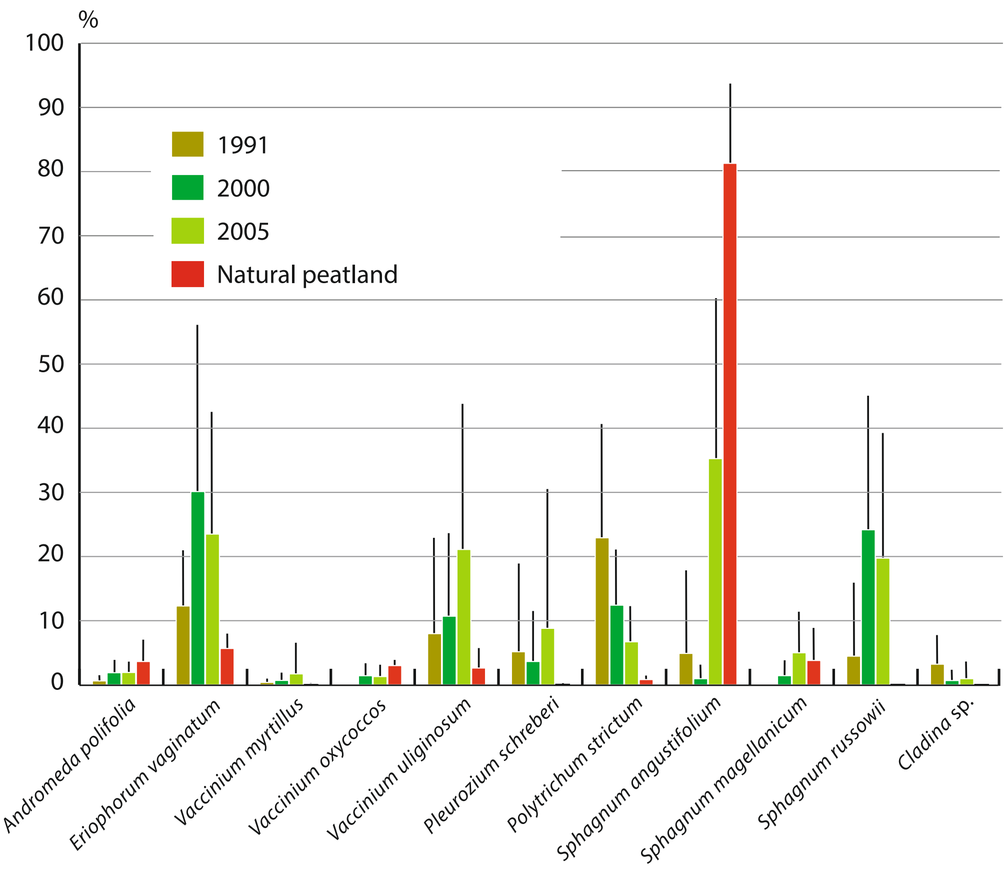


Figure 68. *Aerial photograph of Haapasuo Bog from 1953. Before the peatland was drained most of the water in the catchment area flowed past the marked monitoring point.*

Figure 69. *Aerial photograph from 2004, when most of the restoration work had not yet been realised. The orange line marks the boundary of the Natura 2000 site.*

Figure 70. *Average cover figures for plant species (n = 24) and standard deviations observed 1 (1991), 10 (2000) and 15 years (2005) after ditches at Haapasuo were dammed. The fourth column shows the average cover figure and the standard deviation for the respective species as observed in ten comparable natural peatlands.*



during drier spells most of the water consists of groundwater discharged by springs, which is clear with high pH and high alkalinity, sometimes even higher than 0.2 mmol/l, which is a typical value for groundwater from esker formations. In peatlands such values indicate meso-trophy or meso-eutrophy. The pH of the runoff is over 6 for a large part of the growing season.

Observed water quality parameters only changed relatively little after the further restoration was implemented. Total phosphorus concentrations rose from very low initial levels of some 12 µg/l, to a high in 2005 with double the initial levels, before declining steadily back to 16 µg/l in 2007. Increases in total nitrogen loads were also of the order of a few tens of percentage points: from a starting point of 0.5–0.6 mg/l concentrations increased to about 0.7 mg/l following restoration.

Concentrations of dissolved organic matter also rose to some extent after the further restoration work. Iron concentrations in Säynätlampi Pond were quite high, averaging more than 2 mg/l both before and after the restoration measures, indicating the low oxygen levels in the groundwater that flows into the peatland from the neighbouring esker formation.

These trends in water quality parameters have overall been in a similar direction to those observed in monitoring sites in other restored peatlands, though somewhat less pronounced. Regarding phosphorus, the further restoration work evidently mobilised a total of about 0.1 kg per hectare of restored peatland, which is only a few percent of the highest specific loads observed for restored peatlands. The high iron concentrations in runoff show that there is also plenty of iron present in the peat, and this in itself reduces phosphorus leaching (Zak et al. 2010). The low concentrations of phosphorus also imply that the peatland was not fertilised after drainage. It is also possible that the dams built in ditches in 1990 already mobilised most of the easily leachable phosphorus in the area, leaving less available to be leached following the additional restoration measures realised later.

11.6 A complex of peatlands and small water bodies: Suurisuo, Pihtipudas

Reijo Hokkanen

The aapa mire Suurisuo lies in Central Finland 16 km NNW of Pihtipudas. Restoration work was realised here in 2009 in various hydrologically interconnected habitats: a pond whose water level had dropped, a dried-out stream, drained fens, and areas of undrained fen that had nevertheless dried out (Figure 71). The total area to be restored was 39 hectares in extent.

Suurisuo mainly consists of aapa mires with poorly developed surface microtopography and no large open flarks. The central parts of the aapa mires are mainly mesotrophic flark fens. There are also small areas of raised bog with the features of nutrient-poor short sedge pine bogs. An esker formation almost 2 km long extends through the protected area, surrounded by peatlands.

The situation before drainage

Conditions in the peatland and water flows prior to drainage were studied by comparing old and new aerial photographs (Figures 72 and 73) and by conducting field surveys.

Suurisuo's flark fens and their water flows were surveyed to discover the source of their water. All of the peat-

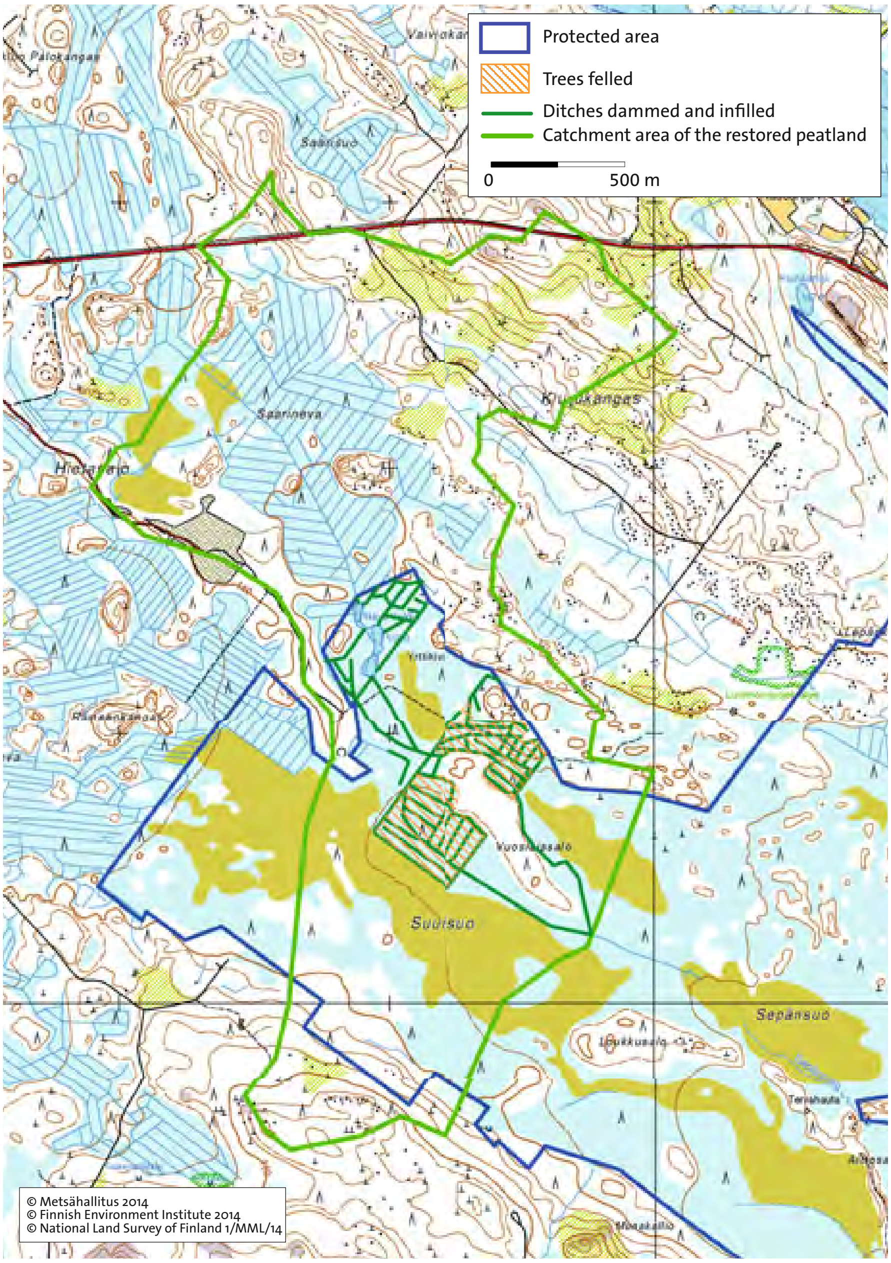


Figure 71. *Restored areas around the isolated patch of forest Vuosiaissalo and Neva-Kukko Pond.*

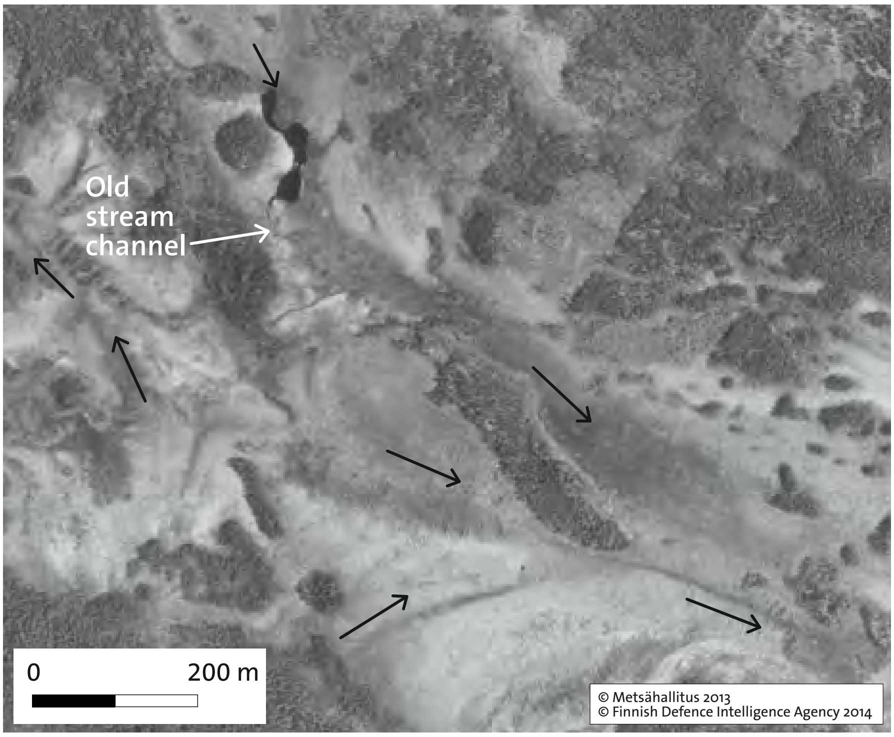


Figure 72. *On an old aerial photograph a stream can be seen flowing from the pond towards the flark fen. The black arrows indicate flow directions.*

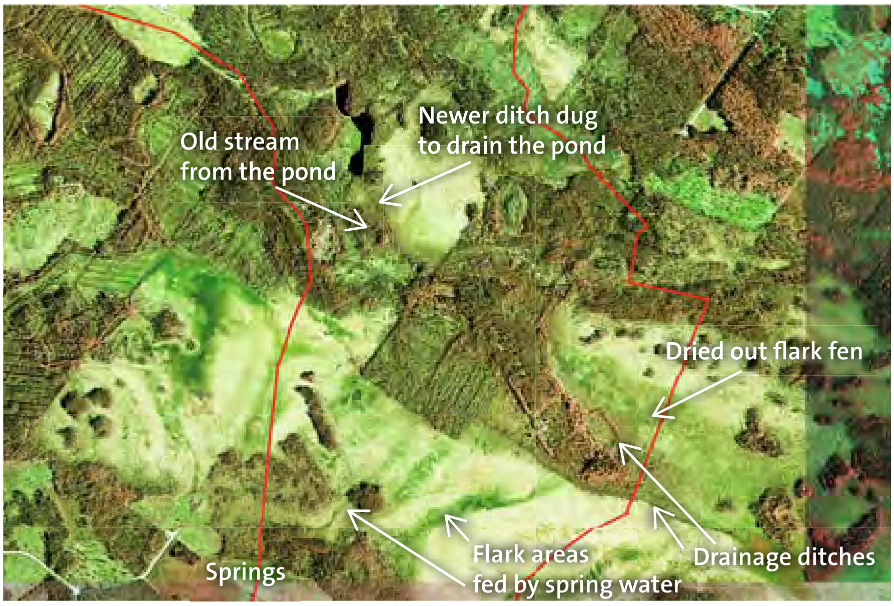


Figure 73. *This aerial photograph, taken before restoration, shows how reddish coloured white birches have grown along the course of the old stream channel.*

lands located outside the protected area but within the catchment area of the peatland to be restored have been drained. This may affect water quality and volumes flowing in the peatlands to be restored.

The area to be restored originally received water from two main directions to the northwest and southwest (Figure 71). Since there are eskers in the area it is likely that the peatland is also fed by groundwater to some extent, but clear signs of the locations of such groundwater discharges were not observed. The old aerial photographs indicate that the pond's shores consisted of fens, and from it was flowing a small stream (Figure 72). The fen south of the forested island at Vuosiaissalo received water from the southwest as well as some groundwater.

The situation after drainage

Suurisuo was drained in the 1970s. A ditch was dug from the pond through the whole of Suurisuo, lowering water levels in the pond (Figure 73). Pines were planted in the fens around the pond, so by the time the site was restored these trees were around 40 years old. The old stream channel had dried out and was only visible as a gully with different vegetation from the surrounding areas. No water flowed in the channel any more, and white birch thickets had grown along its margins. North and south of Vuosiaissalo ditches had been dug in a rectangular grid, with pines subsequently planted. In the former flark fen north of Vuosiaissalo white birches also sprung up, as well as a few lodgepole pines. The water drained from the pond was channelled into ditches south of Vuosiaissalo, though they had earlier naturally flowed through the peatland north of Vuosiaissalo. Ditches had been dug around Vuosiaissalo, joining to the southeast of this patch of forest. Ditch digging had ceased in the middle of the fen, resulting in swamp-like conditions. The ditches dried out even undrained parts of the peatland, especially northeast of Vuosiaissalo, where they interrupted the natural flow of water to the flark fen.

Objectives for restoration

The most important goal was to restore natural flows of water in the area:

- Water had to be channelled into the course of the stream that had earlier flowed from the pond, also raising water levels in the pond.
- Water from the pond was to be diverted north of Vuosiaissalo enabling it to spread over wide areas of former flark fen instead of being channelled through ditches south of Vuosiaissalo.
- Water also had to be diverted into undrained areas of flark fen, especially NE of Vuosiaissalo.
- The extensively drained areas on each side of Vuosiaissalo had to be allowed to revert to open peatland to reduce evapotranspiration from trees.
- Three measuring poles were sunk along the shores of the pond to monitor future water level rises.

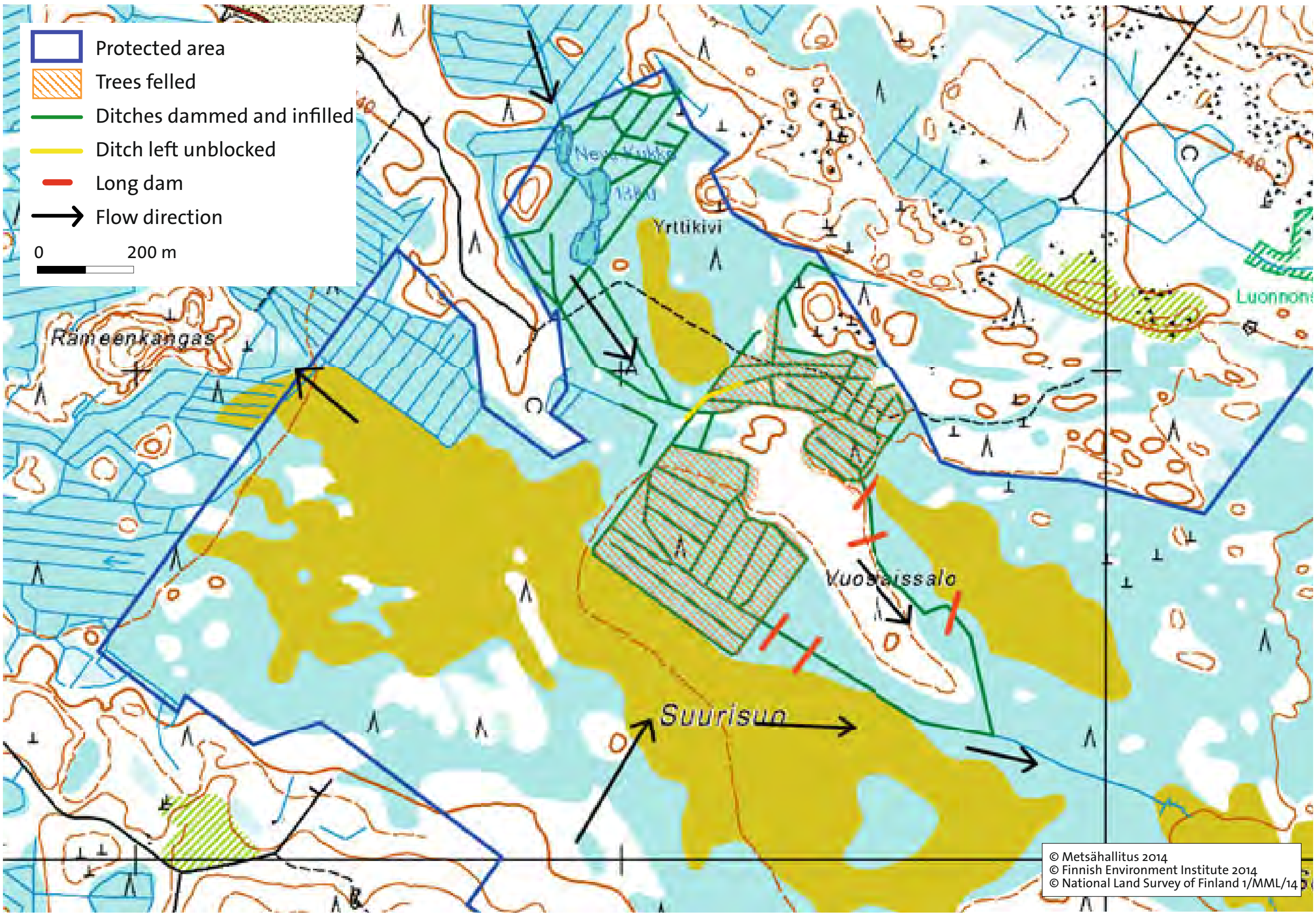


Figure 74. *Trees were felled in the drained areas on both sides of Vuosiaissalo. There had not been much tree growth in other areas. Long dams were built to try to divert the water into undrained areas of fen. By the NW corner of Vuosiaissalo a stretch of ditch was left unblocked to enable water to be channelled to flow north of the forest island.*

Restoration

Restoration work commenced in February 2009 with tree felling (Figure 74). All of the pines that had grown after drainage ditches were dug in an area of 17 ha on either side of Vuosiaissalo were felled for sale as pulpwood or energy wood (Figure 75). A forestry machine was used, though some trees were felled manually. Birches were left standing to prevent the sprouting of thickets.

Ditches were infilled from September 2009 by an excavator. The order in which the ditches would be infilled was carefully considered, since a lot of water flows through the site, and filling in ditches in the wrong order could have hindered the subsequent work of the excavator. The first ditches to be infilled were those immediately around the pond, followed by the ditch draining the pond, so that the pond's water levels would immediately start to rise. Ditches south of Vuosiaissalo were blocked next, to redirect water into the still unblocked ditches north of Vuosiaissalo. These ditches were then blocked, before finally the drainage ditches dug around the southeast end of Vuosiaissalo were infilled.

At the northwest end of Vuosiaissalo about 50 m of ditch was left open just where the stream channel ended (Figure 74), to ensure that water in the stream would be diverted to the north of Vuosiaissalo.

The sites for the most important dams were marked with ribbons to ensure the excavator driver would make them in exactly the right places. Dams were built by existing strings or hummocks where the microrelief was slightly higher. The largest dams (some 20–50 m long) were made in the main ditches of each of the two drained areas (Figures 74 and 76). The goal was that water north of Vuosiaissalo would be redirected into more central parts of the peatland and spread over a wider area corresponding to the former flark fen. The main ditches south of Vuosiaissalo had been dug through the middle of the former flark fen through which water now had to be dispersed. Elsewhere dams were built about 8 metres long.

The situation after restoration

By spring 2010 the water level in the pond had risen about 50 cm. Water had successfully been redirected into the old stream channel (Figure 77), even though it was higher than the excavated ditch had been. The channel was full and its immediate surroundings were waterlogged to a distance of a couple of metres. Trees that had grown beside the channel were dying. Water had also encroached onto the peatland around the pond, where some trees were also dying (Figure 78).

At the northwest end of Vuosiaissalo most of the stream water now flows to the north and northeast of the isolated patch of forest, though some water still also flows to the south of Vuosiais-

Figure 75. *The ditches south of Vuosiaissalo in September 2009. The trees had been felled during the previous winter, and the ditches had not yet been blocked.* PHOTO: REIJO HOKKANEN.

Figure 76. *An excavator building a long dam in the main ditch in the drained area north of Vuosiaissalo, October 2009. By the excavator the ditch is near the boundary of an adjoining area with mineral soil. The forest behind the excavator is part of Vuosiaissalo. The water flows from right to left.* PHOTO: REIJO HOKKANEN.

Figure 77. *Water has started flowing again in the original stream from the pond.* PHOTO: REIJO HOKKANEN 2009.

Figure 78. *Water levels in the pond rose some 50 cm after restoration. Photo:* REIJO HOKKANEN 2009.

salo, at least during seasonal flooding. North of Vuosiaissalo water flows on the surface where trees have been felled, after being diverted around dams, spreading over an area comparable in extent to the former flark fen.

The long dam built across the mouth of the main ditch in the drained area northeast of Vuosiaissalo diverts all of the water that used to flow in the old interceptor ditch dug on the edge of the peatland to more central parts of the peatland. In lower-lying areas water has also been successfully diverted away from ditch lines to areas of fen habitat that had earlier dried out. Areas south of Vuosiaissalo seem to have become quite evenly waterlogged. The wettest areas are around the mouth of the main ditch, where long dams have spread water over the flark fen. Large pools of open water have formed here.

Overall, the goals of restoration seem to have been successfully reached with regard to water flows. The restored area can evidently be left to develop naturally unaided by any further restoration measures.

11.7 Peatlands in Seitseminen National Park

Pekka Vesterinen and Tapio Lindholm

Seitseminen National Park was established in 1982, encompassing extensive areas drastically affected by commercial forestry as well as valuable natural areas. More than half of the park's total area of about 4,500 ha consists of peatlands. Some 60% of this peatland area has been drained at some time, and most of the park's forests have been used for forestry.

The park's surviving natural peatlands are mainly small, fairly dry wooded raised bogs. Old aerial photographs indicate that prior to their drainage the park's larger peatlands mainly consisted of wet, sparsely wooded or open minerotrophic fens or pine fens. About 10% by area are spruce mires, which have been widely drained.

Restoration methods began to be tested here in 1987 (Seppä et al. 1993). A comprehensive plan was drawn up due to the scale of this work (Heikkilä & Lindholm 1994). The idea was to also create a model for peatland restoration plans for other protected areas. The first handbook for peatland restoration was also produced at this time (Heikkilä & Lindholm 1995a).

The restoration plan covered some 1,250 ha of peatland that were almost entirely restored over the period 1993–2005. A further 100 ha of peatland were also restored in areas later added to the park. This plan and its implementation constituted the first ever peatland restoration project to be realised in a protected area in Finland. Monitoring studies of the impacts of restoration on water bodies were also pioneered at Seitseminen (Info box 4).

The whole project aroused widespread interest, and the resulting experiences have been utilised both in Finland and abroad. The scheme's goals and outcomes were also publicised among the international scientific community (Heikkilä & Lindholm 1995b and Heikkilä & Lindholm 1995c).

Planning restoration

The restoration plan was drawn up with reference to old and new aerial photographs (Figures 79 and 80) and field observations. Two basic principles were defined for restoration, with the goal being to re-establish near natural hydrological conditions and recreate near natural landscapes.

Ditches were infilled, but only dammed in exceptional cases, aiming to redirect water flows back to their original pathways away from ditches.

It was seen as particularly important to infill the interceptor ditches dug around the edges of peatlands. Trees that had grown since drainage were removed, both to recreate the original open landscapes, and to reduce evapotranspiration. The plan also prioritised the restoration of wet, open peatland margins, spruce mires, springs and streams.

The plan did not address the impacts of the fertilisation of the area's peatlands for forestry purposes, realised at the same time the peatlands were drained. It later became evident that fertilisation will continue to have clear

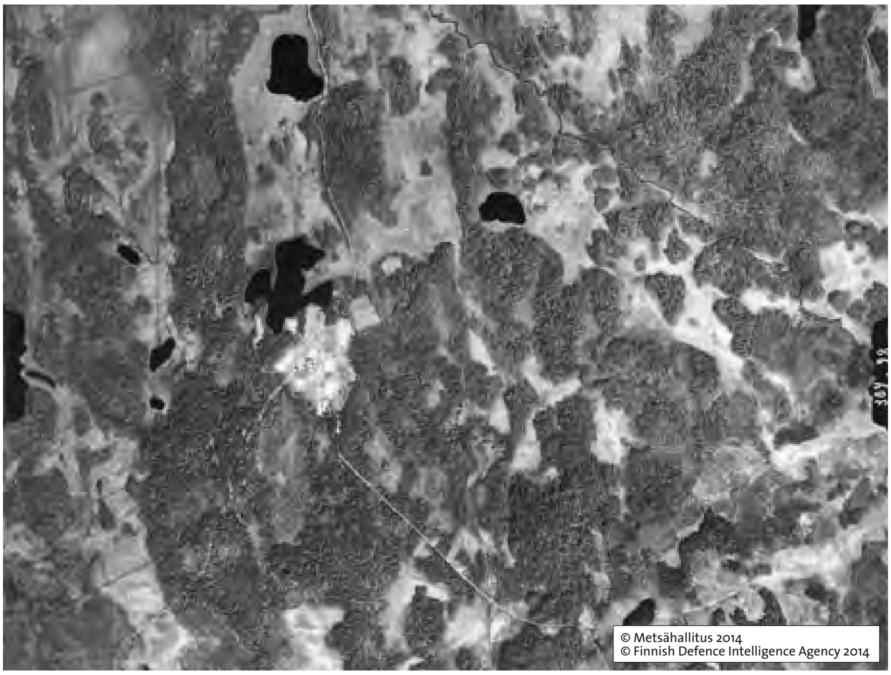


Figure 79. *Aerial photograph of Seitseminen from 1941, before the area was extensively drained.*

Figure 80. *Aerial photograph from 1995, three years after restoration. The arrow marks Kirkkaanlamminneva Fen (see main text).*

Figure 81. *Aerial photograph from 2011.*

impacts on the vegetation of restored peatlands, including the proliferation of cotton grasses for a few years after restoration. Fertilisation also affects tree growth quantitatively and qualitatively, as well as nutrient concentrations in water flowing out of restoration sites.

Restoration

Ditch infilling

The first ditches were infilled at Kirkkaanlamminneva Fen (Figure 80) by an excavator in autumn 1992, using peat and small-diameter trees felled alongside the ditches. No peat embankments were made.

It was soon noticed that using trees for infilling in effect created underdrains, enabling water to continue flowing along the ditch lines. Carefully infilling ditches with peat alone was found to be the best way to slow water flows. However, in the absence of peat embankments water still flowed along the old ditch lines on top of the peat.

From the second year of restoration onwards, ditches were infilled with ditch spoil and peat from the surrounding peatland. Earth was only used to infill certain interceptor ditches and ditches dug through areas with mineral soil. On the basis of conclusions drawn during the first monitoring inspections peat embankments were also subsequently built to slow flows of surface water. Decisions on the siting and sizes of these embankments were made case by case.

In some places ditches were dammed but not infilled, e.g. largely overgrown ditches, ditches in locations near paths, and ditches in very wet areas. In some drained areas the water levels in peatland pools were raised back to more natural levels with the help of dams, to facilitate the restoration of the surrounding peatland.

Measures for tree stands

During the first years of restoration trees were felled manually during the winter after ditches were infilled. Saleable wood was transported by forest tractor to the roadside. But to cut costs and speed up work mechanical felling was introduced, though trees were still felled manually along ditch lines in most areas. During later restoration work machines were also used to remove saleable timber felled along ditch lines. After a couple of unusually mild winters, trees started to be felled before ditches were blocked.

Small-diameter trees and logging residues were piled up on the peatland for burning, usually carried out during the late summer after ditches were blocked. Later, small-diameter trees were collected from sites near roads for sale as energy wood or for use as firewood in the national park's campfire sites. Several frozen winter roads were created to facilitate the transportation of saleable timber, leading to considerable cost savings.

Costs and income from timber sales

The total costs of the restoration work realised at Seitseminen amounted to some 1.2 million euros (including wage costs and fees paid to contracting firms), averaging €888 per hectare. There were great differences in cost levels between different sites, largely due to the varying need for tree felling. One of the most costly aspects of the restoration work was the piling up and burning of logging residues.

Approximately 17,000 m^3 of saleable timber was obtained, generating income of some €0.75 million.

Key outcomes and conclusions

The desired reversion towards a near natural state can be seen to have commenced successfully. The situation is most favourable in areas fed by significant amounts of water from higher-lying natural mires. The opportunity to restore entire catchment areas also seems to have been fruitfully realised (Figure 81).

Valuable experiences of ditch-blocking methods, the time taken and the costs involved, were built up and subsequently utilised. Restoration methods were enhanced greatly during the project. Changing to mechanical tree felling made the project more cost-effective. The need to make peat embankments in addition to blocking ditches became evident, and the use of trees to block ditches was abandoned.

The most significant problems concerned the early phases of restoration, the growth of thickets, and the leaching of nutrients. At Kirkkaanlamminneva water still flows in some blocked ditches, thickets of seedlings have grown profusely in places, and water quality has temporarily declined in some lakes and ponds.

Changes have occurred in vegetation to varying degrees: in some peatlands changes have been rapid and in line with the project's objectives, but elsewhere progress has been slow and patchy. Most peatland plant and animal species have successfully recovered, with forest species correspondingly declining.

Further complementary measures under consideration include the clearing of seedling thickets in some places and the construction of more robust dams at Kirkkaanlamminneva.

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Ecological restoration has been widely practiced in peatlands in protected areas in Finland over the last 25 years. This guidebook is based on the wealth of knowledge and experiences accumulated during these years. It gives an overview of the practical methods applied in the ecological management and restoration of peatland habitats in Finland together with useful background ecological information on peat and the hydrology of peatlands. The aim of this guidebook is to increase understanding of the ecological base for peatland habitat restoration, and thereby promote effective peatland restoration work both in protected areas and in areas where commercially forestry is practised.

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