Restoration of peatlands drained for forestry

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Acknowledgements

When first planning this project I didn't know what to expect - I was asking people I had never met, from far away, to share their time and experiences with me. As it turned out I had no need to worry. The people I met on my study visit were more than willing to share their time and experiences with me, and for that I cannot thank them enough.

I was impressed by the energy, the enthusiasm and the passion of the people I met while on this visit and it gives me pleasure to think that such people are the scholars and custodians of the peatlands. I would therefore like to warmly thank the following people for the welcome I received and time they took out from their regular work to show me the peatlands and contribute their ideas to this report. These people are: Tiina Heikkinen, Erwan Stricot, Harri Vassander, Pekka Vesterinen, Jouni Penttinen, Reijo Hokkanen.

I would also like to thank my girlfriend Lara Heppenstall and supervisors Roxane Anderson, Richard Payne, for their help, advice and enthusiastic support. I would also like to thank the people at Europarc, particularly Meldra Langenfelde and the Alfred Toepfer Foundation for the assistance in planning and the financial support for this project.

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Project Summary

Peatlands are the largest and most space-efficient form of terrestrial carbon storage. After agriculture, conversion of peatland to forestry is the biggest land-use change driving the loss of peatlands. Much of peatland forestry has been commercially unsuccessful and has caused a decrease in biodiversity, along with a destabilisation of the long-term carbon store. Peatland restoration is now underway across Europe, but important questions about the long-term effectiveness and the most economic forms of restoration still need to be answered.

In the autumn of 2015 I secured funding to visit peatland restoration projects in Finland. While there I visited Metsähallitus, one of the pioneering organisations involved with the restoration of afforested peatlands. I also visited the 'peatlanders' at the University of Helsinki, who have produced a herculean portion of the research on forested peatlands in recent years. This was done with the aim of gathering information on peatland restoration which may be of relevance to projects across Europe, particularly those in the north of Scotland.

Several messages came up time and time again throughout my visit. One of these was the importance of hydrology to restoration above all else, with the strong recommendation of prioritising ditch-filling and damming.

I perceived some uncertainties about the effect of restoration on the carbon balance of bogs, which is likely due to the diversity of sites and variable effectiveness of drainage that can be observed in Finnish peat forests. Therefore restoration at the moment is primarily being driven by the well-established benefits to biodiversity. However understanding of forested peatland carbon dynamics is improving, and provides a strong argument for the restoration of certain types of bogs, particularly when the bog vegetation has been destroyed and peat accumulation halted.

Research at the University of Helsinki indicates that the retention of bog species makes forested peatlands less likely to be carbon sources. Unfortunately, sites that are likely to have the highest carbon losses from peat, the dense forests situated on nutrient rich sites, are also the most controversial to restore due to their commercial value.

When planning which areas to restore, decision makers should consider the effects on biodiversity, carbon dynamics and the social value of sites, and where they can get the best value for money spent.

The ideal sites for restoration are those where:

- the damage to biodiversity has been great
- the land is cheap due to the forest being uneconomical
- the bog vegetation has been lost or highly modified
- the sites have a high potential value for education and recreation.

Introduction

What are peatlands?

Pealtands are a type of wetland that accumulates dead plant material over time and stores it as 'peat', a form of organic soil with a very high carbon content.

Peat, and peatlands are formed due to a fundamental imbalance between vegetation growth and decay. This imbalance occurs due to the decay-resistant properties of peat-forming species, such as *sphagnum* mosses, combined with favourable climatic and hydrological conditions. Peatlands are found across all regions of the world, including such diverse places as Scotland, Uganda and Argentina, with the only exceptions being the driest and most arid regions.

Why care about peatlands?

Peatlands have not always been the most favoured of ecosystems - for much of recent history they have been viewed as little more than wasteland, ripe to be drained, burned and planted "The wide desert where no life is found" (Macdonald 1945) . They were the force of nature to be conquered, the wilds yet to be tamed. However this attitude is changing as the needs of societies change. The value of peatlands is better understood now than ever before. Intact peatlands are important for storing carbon and mitigating greenhouse gas emissions, along with providing habitat for a variety of rare plants, insects and migratory birds. Healthy peatlands are able to dampen rainfall events and thus decrease the likelihood and severity of flooding, while filtering out nutrients and improving water quality. They now provide valuable recreation space and much sort for 'wild land' in the sense that human presence is most lightly felt in these areas. In some parts of Europe, such as Finland, they are places where people can harvest berries, which are an important supplement to rural incomes. For these reasons and more healthy peatlands are valuable to society.

Peatlands and carbon storage:

Arguably one of the most important reasons to care about peatlands is the immense amount of carbon stored within them. Over 20% of terrestrial carbon is stored as peat - a similar amount as is contained in the atmosphere - despite peatlands only covering 3% of land surface area (Yu 2011; Dise 2009). Much media attention has been given to the plight of the tropical rainforest in recent years, with peatlands going virtually unmentioned. However the average carbon density of peatlands is almost twice that of tropical rainforest (Adams, Faure, Faure-Denard, et al. 1990), and unlike the rainforest the capacity of peatlands to store carbon is practically unlimited (Belyea & Baird 2006). Since the end of the last glaciation carbon sequestration by peatlands has had the effect of cooling the climate by an estimated 1.5 – 2 degrees Celsius (Holden 2005).

In pristine bogs this carbon store is relatively stable, with very slow long-term rates of decay. Carbon can be expected to be stored for thousands if not tens of thousands of years, with the rate of new peat formation outstripping the slow rate of decay in the older deeper layers, causing a slow but steady accumulation of carbon. This is not the case for peatlands that have been subject to drainage or other forms of disturbance. Peatlands that are drained or have lost their native vegetation can rapidly become sources, and can oxidise and disappear altogether over time, releasing this carbon store into the atmosphere.

FAOSTAT, a United Nations body, estimates that drained peatlands covering 0.2% of the earth's land surface, emit 1 gigaton of greenhouse gas emissions every year. It is likely that this figure may increase if drained peatlands are subject to warmer and dryer climatic conditions under a changing climate.

Conservation value

Undisturbed peatlands are becoming increasingly rare in Europe and as such many of the species that depend on them are in decline. One example is migratory wader birds, such as the greenshank and the dunlin. Prior to the flow country's drainage for forestry, 70% of the UK greenshank population was found in this large peatland in the north of Scotland, As such the UK greenshanks were vulnerable to attempts to drain this peatland, and their population suffered greatly as a result of habitat loss.

Certain types of peatlands are more vulnerable to destruction than others. For example 94% of lowland raised bogs have been lost in the UK, mostly to conversion to agricultural land, and much of the specific flora and fauna that is associated with them is now very rare. Similarly nutrient rich fens in Finland have been particularly favoured for drainage due to their suitability for uses such as agriculture and forestry, and these sites and associated species have also become very rare.

Landscape value

Peatlands mean different things to different cultures. In a modern democratic society it is inadvisable to exclude people from a landscape, even for the purpose of protecting it. Few people will fail to be impressed by the scale, the dramatic landscape and the diverse nature of peatlands. They are frequently featured in Scottish tourism brochures, and it is claimed that Finland is even named after them being a corruption of the English word 'fen-land'. Peatland protection and restoration need local support and the best way to do this is to promote use and access to tourists and the local community.

Scientific value

"To the ordinary man mires are not only lonely and monotonous but even uninteresting, and when one wanders for a mile after mile over the unvarying surface of the bog it may seem difficult to dispel such an impression. But it is nevertheless a mistaken one. One only has to persevere to reveal a whole series of fascinating details, to discover that these mires mirror variations in climate, topography and soil conditions, that in fact the interplay of these factors makes its impression upon the history of the mire" – Hugo Osvald (peatland palaeo-ecologist) 1952

Peat accumulation creates a unique and irreplaceable record of vegetation, environmental change and human activities which cannot be replaced. Cereal grains and pollen found in peatlands has allowed archaeologists to date the spread of agriculture, while tree remains and pollen have been able to show how the climate has changed over thousands of years. As peatlands dry out and subside this record become more and more difficult to interpret and as peatlands are lost, the information they contain is lost with them.

Threats to peatlands

Peatlands often appear to be some of the last untouched areas in Europe. Those that remain are often located in remote areas and places where the climate historically provided a challenge to human habitation. These peatlands often appear to be teeming with wildlife and are wet, boggy and difficult to traverse. You could easily believe the human interactions with these ecosystems to be minimal, however the truth is really quite different.

With industrialisation over the past few centuries the pace of peatland drainage has increased dramatically, and the stability of this carbon store is increasingly called into question. For northern temperate peatlands drainage for forestry is the main driver behind land conversion, and this holds true in both the UK and Finland. Emissions from these sites vary greatly depending on factors such as the nutrient status of the sites, the effectiveness of drainage, the timescale considered, and the end use of forest products. However forest peatlands have the potential for high carbon emissions, with peat respiration due to microbial decay ranging from approximately 0.5 to 2.5 kg C m^{-2} per year in Finnish peatlands (Ojanen, Minkkinen, Alm, et al. 2010). In Scotland emissions from degraded soils are estimated to be higher than the emissions from the entire transport sector (Bain et al. 2011).

Forestry and Peatlands

Globally 4% of peatlands, or 15 million ha, is estimated to have been drained for forestry (Zoltai & Martikainen 1996), second only to agriculture as the leading cause of peatland drainage. The hyperoceanic climates of the UK, Ireland and parts of Norway favour naturally treeless bogs, while the more continental climate found in the rest of Europe naturally favours forested peatlands, where trees grow amongst peat-forming plants.

This has led to two fundamentally different forms of forestry, the British and Irish technique that relies on intensive management through ploughing, planting, thinning and fertilising and the less intense method favoured in much of Europe that relies primarily on drainage and natural regeneration.

Restoration of peatlands drained for forestry

Climate scientists have described peatland restoration as a “low hanging fruit”, a way we can prevent carbon emissions at reactively little expense (Bain et al. 2011), however peatland restoration is still in its infancy. Important questions remain, such as the priority of sites to restore, the effectiveness of more economical methods, and whether some of the more drastically altered sites can ever again function as viable peatland. An estimated 1.9 million ha of peatland has been drained for forestry across western and central Europe (Armentano & Menges 1986) and in the UK and Finland the proportion of peatlands drained for forestry is high, with as much as 20% and 54.8% of peatlands respectively having been converted to forestry (Patterson & Anderson 2000; Cannell, Dewar & Pyatt 1993; Turunen 2008).

Many of the sites drained for forestry in both the UK and Finland were not suitable for forest growth and proved to be highly uneconomical, while simultaneously putting the carbon stored there at risk. In Finland 10-15% of peatland drainage has had little or no effect on tree growth, and in the UK the expenses of extracting the timber can often outweigh the value gained from the wood. Peatland forests are often uneconomical as they tend to be planted at high altitude, in exposed conditions where growth is poor and wind-throw risk is high - this means the trees have to be harvested before they reach maturity and are frequently toppled by the wind.

Forest to bog restoration in the UK has begun on a large scale in the last decade (figure 1,2), and much of the work is highly experimental. At the RSPB Forsinard reserve in the north of Scotland restoration techniques involving the blocking of ditches and the crushing and removal of trees are underway, but it may be many years before the results of such studies are available. It will require decades of work to answer big overarching questions, such as "what is the minimal amount of resources that need to be put into restoration to achieve a satisfactory result"?

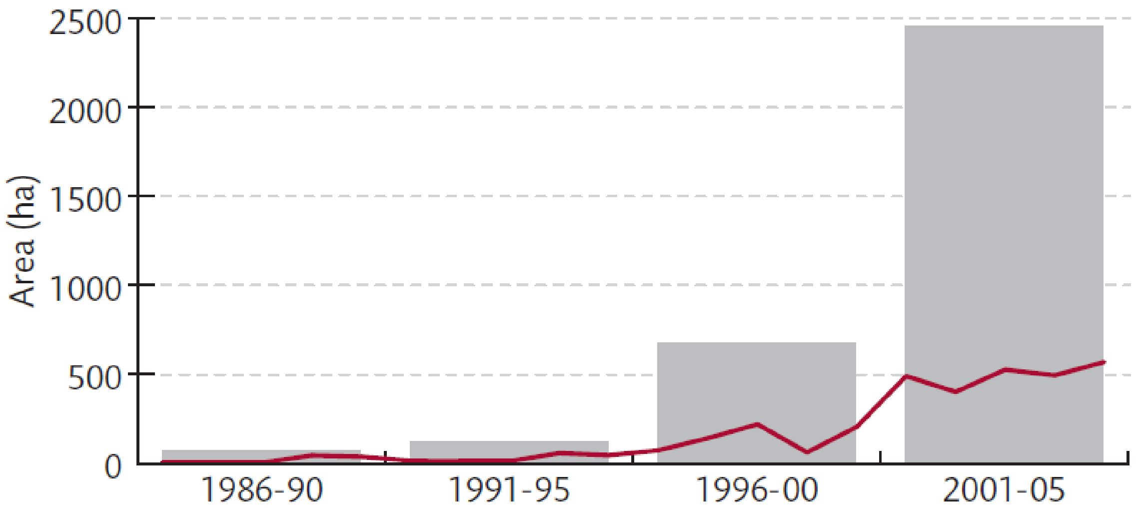

Figure 1. The area of afforested peatland restored in the UK from 1986 to 2005: results of current research 2010

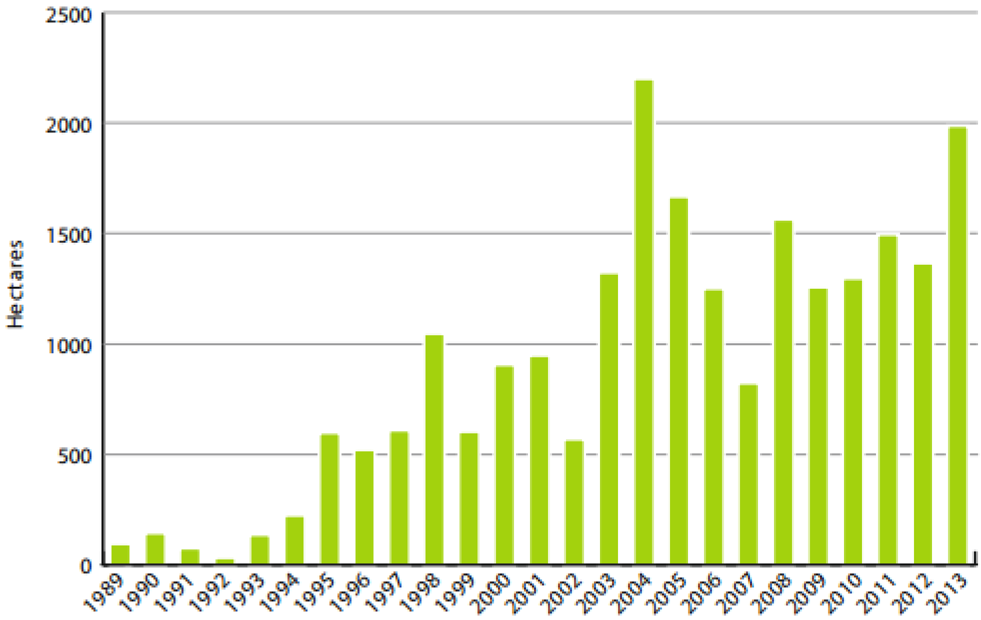

Figure 2. The area of peatland restored in Finland annually in state-owned protected areas 1989-2013: from Similä, Aapala & Penttinen (2014)

Metsähallitus, the state organisation responsible for forestry and administration of Finland's national parks, has been undertaking a peatland restoration program for over 25 years and over this time has gained many answers to these big questions. The current phase of their restoration work aims to restore 4300 ha of bog in 54 Natura 2000 sites over a period of three years. They have also recently published a handbook on peatland restoration, making them the ideal organisation to visit to learn about bog restoration.

During my visit I learned more about the differences in ecosystem function of open, natural, and drained peatland forestry. This complemented a small project I worked this summer investigating forest-to-bog interactions in western Siberia, funded by EUINTERACT. Among other things, this project looked at changes in hydrology and biodiversity. There is a move within UK forestry to try and promote less intensive forms of afforestation, such as the use of natural regeneration. This is already being practised in Finland and this visit allowed me to compare the less intensive Finnish management with the natural and intensive forests I'm currently working on.

Environmental Research Institute (ERI), the organisation where did my MSc, is involved in a project to promote the use of biomass energy. With our help a £2.5 million biomass heating boiler was installed in the nearby town of Wick to run the district heating scheme. This provided a use for some of the timber felled during bog restoration, lowering the cost of felling operations, and enabling the use of more whole tree harvesting which we believe will allow the bog to recover faster. In the future we hope to expand schemes such as this in the highlands and I believe we could learn a lot from Finland, where 20% of energy is generated from wood biomass.

I believe that Europarc members, along with myself and my colleagues, greatly benefited from the vast amount of experience that Metsähallitus has in managing and restoring peatlands. It is my conviction that, if communicated properly, we can use that experience to restore those afforested peatlands, which are currently strong carbon sources, more rapidly and more effectively, into carbon sinks. In addition to the climate benefits this will bring about, the restoration of these peatlands would help promote biodiversity, which has been shown to be greater in natural bog systems. This also provides an important opportunity to improve the health and wellbeing of European citizens through restoration of damaged ecosystem services, such as the provision of clean water, recreational value and flood prevention.

Given the vast amount of carbon stored in damaged European peatland and the potential these sites have to act as both as a carbon source and sink, I believe a good stewardship and effective restoration of our peatlands should be one of the top priorities for conservation in Europe.

Summarised Itinerary

17th August - Torronsuo, Lahnalamminsuo

18th August - University of Helsinki

19th August - Tervalamminsuo Lettosuo

20th-23rd August - holiday in Helsinki, travel time to Parkano

24th -25th August Seitseminen National Park

26th August -Kauhaneva-Pohjankangas

27th August - Lauhanvuori National Park

28-31st August - holiday time in St Petersburg and travel to Petrozavodsk

1st-5th September - Mires of Northern Europe conference Petrozavodsk, Russia

6th September - travel time to Viitisarri

8th-9th -September - Salamajärvi National Park

10th September - Pyha-hakki National Park

20th September - departed Finland

Figure 3. Map of sites visited during this study visit

Detailed Itinerary

Torronsuo

On my first field visit in Finland I met Tiina and Erwan, who are studying CO_2 and methane emissions from restored, drained and natural peatlands as part of their MSc work with Harri Vassander. After leaving Helsinki University we drove to Torronsuo National Park which is located about two hours away. Torronsuo is the largest mire in Southern Finland, and remains, for the most part, in a natural state. One exception to this is the northern edge of the mire, which has been drained for forestry. An area of 150 Ha was restored in 1998 as part of an 'EU life' project. Torronsuo has a high conservation value, as it is home to a variety of wetland birds and acts as a 'staging post' to over 1000 migrating cranes. The natural peatland at Torronsuo is classed as an ombrotrophic pine bog, meaning it gets nutrients only from atmospheric input - because of this it is also 'oligotrophic' or very poor in nutrients. What nutrients the bog gets from the atmosphere are quickly absorbed by the sphagnum mosses, and locked away in an inaccessible form within the peat. After drainage and management for tree growth these sites typically turn out to be commercial failures. The drained sites are classified as 'Jätkg', which is nutrient poor and sparsely forested, as can be seen in Figure 4. However on the ground the difference in tree cover and surface wetness is apparent between the restored bog (Figure 5) and natural areas (Figure 6). However, despite the unsuitability of peatlands such as this for tree growth, a combination of unfounded optimism and government subsidies led to over 100,000 ha of this type of peatland being drained for forestry.

Figure 4. Drainage channels seen from aerial photos at Torronsuo - note how tree cover is relatively sparse

Once we arrived at Torronsuo Tiina and Erwan started work measuring the greenhouse gas fluxes. It is possible for them to measure CO^2 fluxes in the field using a EGM, environmental gas monitor (Figure 6). Measuring methane fluxes is harder though, requiring gas samples to be taken from the site and analysed in the lab. Measurements are taken using chambers attached to collars in the ground (to provide a good seal and to minimise disturbance to the peat surface). Tiina and Erwan sampled from different areas of the bog, including the filled in ditches and the drier hummocks. Although the project is ongoing, it is not unusual for them to record CO^2 fluxes an order of magnitude higher in the drier hummocks compared to the wetter former ditches. As part of the restoration process sphagnum growth is being measured using a plastic net (Figure 6). Sphagnum is very important for peat formation and a long-term recovery of sphagnum growth would be indicative of successful restoration.

Despite the site being valuable for conservation, or perhaps because of it, Metsähallitus (who manage Torronsuo) have a philosophy of making the peatlands freely accessible and encouraging recreational use. There is a tower from which the mire can be viewed and also a marvellous network of boardwalks from which it is possible to cross and admire the mire without even getting your feet wet (Figure 5).

Figure 5. Top left: view from the boardwalk at Torronsuo. Top middle, top right: Carrying out CO_2 and CH_4 measurements in restored peatland at Torronsuo across different microforms, ditches, lawns and hummocks

Figure 6.
Top: pristine peatland at Torronsuo.
Middle: nets used to measure the growth of Sphagnum, a good indicator for wetland restoration.
Bottom: Environmental Gas Monitor used to take CO_2 *measurements from the site in real time -it is not possible to measure* CH_4 *in situ therefore gas samples have to be taken back to the lab*

Lahnalamminsuo

After leaving Torronsuo we visited a drained site which has not undergone restoration, although some of the ditches were filling in naturally with Eriophorum sedge (Figure 7).

The differences in appearance were apparent between this site and the natural and restored sites at Torronsuo. Vegetation here was very dry (figure 8) and there was a higher abundance of shrubs such as *Calluna vulgaris* and *Rhododendron tomentosum*. Although tree cover was quite dense in places the trees were generally thin and spindly, and it is unlikely the site would be commercially viable.

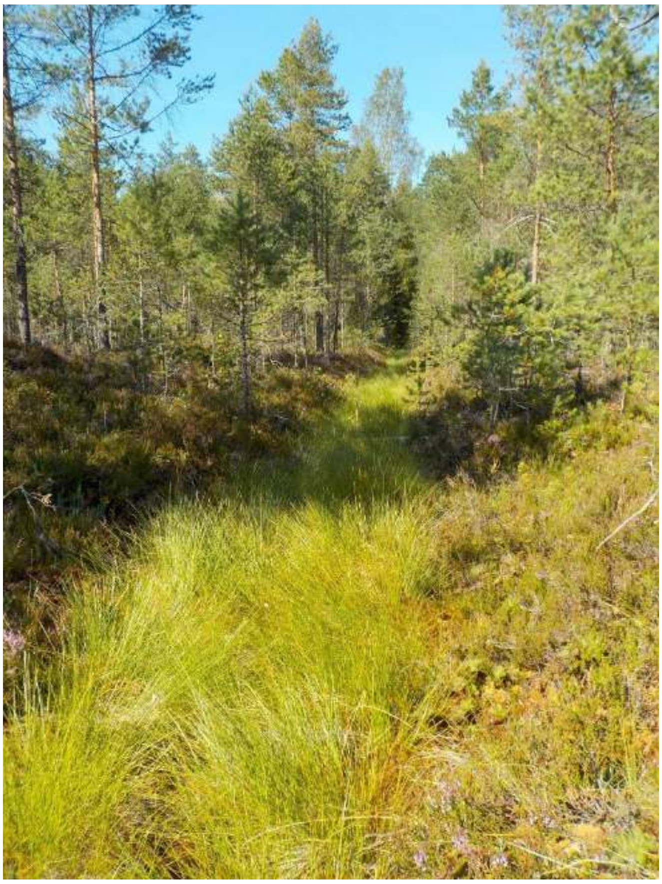

Figure 7. An unmaintained ditch naturally filling in an unrestored peatland -note the dominance of Eriophorum sedge

Figure 9. Unrestored drained peatland at Lahnalamminsuo

Figure 8. Dry peatland vegetation at Lahnalamminsuo

University of Helsinki

This day it was not practical for me to go out in the field so I was instead invited to meet the 'peatlanders' at the University of Helsinki peatland research group. This was very exciting as an immense amount of research on forested peatlands has come out of this group, and they are arguably considered the leading authorities on peatland carbon emissions.

I discussed some of the issues and obstacles around peatland restoration with Professor Harri Vassander and Karri Minkkinen, who are both interested in the carbon dynamics of peatlands and the effects of forestry operations. They had many valuable insights into both the scientific and the practical issues surrounding restoration, a summary of which I will record here along with my own thoughts and related readings.

Speaking in general terms, sites such as the area drained for forestry at Torronsuo are unlikely to be large carbon sources. Such sites are nutrient poor and 'ombrotrophic' which means they get their water and nutrient purely from the atmosphere. Drainage in these sites typically 'fails', in the sense that it is not possible to commercially grow timber and bog plants have continued to persist, although sometimes with a changed species composition. It is not even unheard of for carbon sequestration to increase in these sites when drained, at least in the short term, as the drainage can actually stimulate growth and/or shift the bog species composition towards drier sphagnum moss species which are actually better carbon accumulators than some of the wetter species which may have been previously dominant. Questions remain about how these sites may develop in the future and whether they will eventually, after several centuries, come to resemble the natural peatlands, or whether the drainage will make them more vulnerable to climate change and place these sites on a different long-term ecological trajectory. More than 100,000 ha of peatland drained for forestry is this nutrient poor 'failed' type, so what happens to the carbon in these areas and what impact restoration can have are important questions.

Sites that are high emitters of peatland carbon tend to be more successful for tree growth, these are typically the mineral rich fens and spruce swamps. It is thought that the greater loss of peatland vegetation, due to competition with the trees and the greater success of the drainage, contribute to these emissions.

Restoration of economically productive drained sites is more controversial than the failed sites despite the higher climate value of restoring the former. Forestry and wood products are a major component of the Finnish economy. Though they have both been declining in importance over recent decades they are a key export and still account for 1.9% of Finland's GDP.

Economics must therefore be taken into account when making decisions on which sites to restore. Due to the economic importance of forestry, much of the peatland restoration that has occurred has been in sites that have been commercial failures. Although these sites are in some ways considered to be 'easy' to restore, for example little or no tree felling is necessary and bog vegetation, never fully being lost, is quick to recover. Despite this restoration can be more expensive than in commercially successful sites, where the value of timber harvested often more than compensates for the site restoration costs. It is rare that economically productive peatland forests are restored solely based on their climate impact, these sites also tend to be highly important for biodiversity and conservation. I was lucky enough to visit a few of these sites later on in my visit.

While at the University I also met Jyrki Jauhiainen and Mari Könönen, who are tropical peatland specialists. We discussed restoration of tropical peatlands, which is very challenging to do. Tropical peatlands need high inputs of plant material to sustain peat growth and when the original surface is lost they lose carbon rapidly, most of it in the aquatic form of DOC, which can easily be overlooked as a carbon export. They study an area in the central Kalimantan affected by the 'Mega Rice Project', which was a scheme to drain a million ha of tropical peatlands for rice growth. It also involved the relocation of over 100,000 people to farm the rice. The scheme was a massive failure, resulting in massive carbon emissions and regular peat fires that cause problems with air quality. Leaching of nutrients into the waterways has also been implicated in the decrease in fish stocks and the associated economic problems. The Norwegian state has recently signed a $1 billion agreement with Indonesia to try and reduce the environmental damage caused by the Mega Rice Project. Currently restoration works are focused on raising the water level and preventing the peat fires.

Tervalamminsuo

On my second day out with Tiina and Erwan we visited Tervalamminsuo once again to look at the restored and natural peatlands. At Tervalamminsuo the greenhouse gas monitoring is quite sophisticated and in addition to the chamber measurements carried out by researchers like Tiina and Erwan there is also an eddy covariance tower (Figure 10). The tower continually monitors the greenhouse gas flux, taking measurements several times per second, and includes the fluxes from the trees which is impractical using chambers. The combination of the eddy covariance and chamber measurements is able to give a really good picture of the gas flux and the components of the ecosystem which are responsible for it.

Figure 10. Eddy covariance tower at Tervalamminsuo which is able to measure real-time whole ecosystem CO_2 flux

Restoration work at Tervalamminsuo was completed more recently, in 2005, and as can be seen from the aerial image and photographs (Figure 11) the tree cover is denser than in Torronsuo. Tervalamminsuo is also a nutrient poor ombrotrophic bog, and the timber grown since drainage is not worth harvesting commercially. Restored sites such as this will be monitored, and providing bog vegetation continues to recover and tree cover does not significantly increase the site can be left to recover without further intervention. It is expected that some of the pines will die off as the water table rises.

Figure 11. Left, Middle: restored peatland at Tervalamminsuo. Right: Aerial image of Tervalamminsuo showing the restored and the pristine sites

Lettosuo

A short drive from Tervalamminsuo is the forested peatland of Lettosuo. Here experiments are being done on the greenhouse gas impacts of different felling practices for forested peatlands, one block will be clear-felled, one selectively felled, and another kept as a control. Automatic chambers sample the greenhouse gas emissions from different microforms, while the eddy covariance tower measures the carbon balance for the whole site. Lettosuo was one of the densest forests visited on the trip, with the trees so dense most of the bog vegetation had been lost. Unlike many of the other sites I visited in Finland this one is quite similar to the commercial planted forests of the UK. Unlike the ditches in the restored site, these ditches are well maintained and are draining freely.

Figure 12. Left: ditch recently deepened in a commercially successful drained peatland at Lattosuo. Right: automatic chambers sampling CO_2 emissions within the forest to supplement measurements being carried out using eddy covariance

Figure 13. Eddy covariance tower at Lettosuo monitoring ecosystem CO_2 balance in real-time - eddy covariance towers in forested peatlands are much taller in order to capture the CO_2 flux from the tree canopy

Seitseminen

After my time with Tiina and Erwan in Helsinki I travelled north to Parkano to visit Pekka Vesterinen and the sites managed and restored by Metsähallitus in that region. About 60% of the mires within this park were drained in the 1960s prior to getting protected status. A large amount of restoration work has been carried out at Seitseminen, here there is 500 km^2 of drained peatlands still in the early stages of restoration. The peatlands here are important habitat for the willow ptarmigan and the globally endangered whooper crane.

Seitseminen National Park is a mosaic of peatlands and mineral soil forests. Management of the park is holistic, and seeks to address the landscape as a whole rather than individual components of it. The 'ecotone' or interface between the mineral forest and the peatlands is a hotspot for biodiversity, and this connection to a diverse mineral forest is beneficial to peatland biodiversity. One way of maintaining this diverse mineral forest is by carrying out controlled burning. While I was at Seitseminen I was lucky enough to witness this. These controlled fires are carried out every couple of years, providing the climatic conditions are suitable. Metsähallitus plans to burn 200 ha in Seitseminen over the next 30 years. Controlled burns are necessary to create habitat for species associated with burnt wood such as woodpeckers (figure 14) and the extremely endangered *Phryganophilus ruficollis,* which can fly for hundreds of kilometres seeking wildfire sites. These fires mimic the natural burning of the forest which has been prevented in the past century due to more effective wildfire control. Scots Pine, *Pinus sylvestris,* is highly tolerant of burning, however spruce trees, which left unchecked would eventually outcompete the Scots pine, are easily killed by the fire. Thus by burning the forests the ecological succession is kept in check and the more desirable (in terms of biodiversity) pines are maintained, while the dead spruce trees created by the burn provide valuable habitat that is missing from many managed forests.

Figure 14. Red crested woodpecker, one of the most iconic species that benefits from managed burning (image credit Alastair Rae, available under the creative commons licence)

Burning of these mineral areas is made easier by the adjacent healthy peatlands, which in their natural state are wet enough to provide a natural barrier to the spreading fire.

While at Seitseminen I visited some of the earliest restored sites (Figure 16) and Pekka and I discussed the lessons have been learned from sites like this. The pines on this site were originally thinned out to try and mimic the tree cover prior to drainage, however as the mire was still quite dry at this point birches sprung up to take the place of the pines. Pervious fertilisation of sites also increases the risk of birches taking over and sites that are now nutrient rich can be expected to have a birch problem if the pines are logged. Birches are a major problem for peatland restoration in Finland as they are very difficult to kill, tending to 'thicket' when chopped down. Like the mythical ancient Greek beast the hydra, when one trunk is cut two or more spring back! An additional problem is that the water use of mature birches is higher than pines, so if birches are allowed to grow too big they can negate the effects of ditch filling and maintain a low water table without the need for drainage. It is hoped that at this site the drain blocking will prove effective enough to kill off the birches and none will remain in 20 years time. Already sphagnum mosses have returned despite the birches and their cover is growing. As we progressed further into the mire the birches became smaller, more stunted and sickly looking. This site will be monitored and if necessary further methods will be employed to remove the birches. Currently when sites are restored trees are rarely felled, since if a high water table can be restored many of the trees will die naturally and their remains will be quickly consumed by the growing moss. Some trees are still selectively logged, but often this is due to their commercial value. The proceeds from these trees help to pay for the restoration work.

The third restored site we visited that day was a former forested fen that was drained over 50 years ago but is now being restored. *Sphagnum* mosses are now growing over forest mosses (Figure 15) such as *Pleurozium schreberi* and *Hylocomium splendens,* and luxuriant carpets of sphagnum now cover the former drainage ditches (Figure 18). The spruce trees die off in the wetter areas due to the higher water table, and the streams that were diked and diverted into drainage channels are also being restored.

Figure 15.Peat forming Sphagum overgrowing the forest moss Pleurozium schreberi is a good indicator that the restoration is going well

Seitseminen also has some excellent examples of minerotrophic fens, these sites are more productive than the nutrient poor oligotrophic peats. The carex and sedge species that dominate them are even nutritious enough to provide fodder to reindeer, and farmers used to harvest them as an additional food source for their stock. Due to their higher nutrient status it is much easier to grow trees on fens such as this than oligotrophic bogs like the first site I visited, Torronsuo (Figures 4,6). Thus not many minerotrophic fens are still in existence and this habitat is rare now, especially in the south of Finland. Rich fens like those I was to see in Russia (Figure 27), no longer exist on a large scale in Finland.

Figure 16. A restored site that has been invaded by birch trees after the pines were felled

Figure 17. Pristine sedge dominated fen at Seitseminen which is, naturally treeless, and rovides valuable spring grazing habitat for moose and reindeer when they are present (such sites can be affected by drainage work carried out upstream)

Figure 18. Left: changes in surface vegetation reflect water flow on pristine mires. Centre: restored swamp forest with sphagnum filling a former ditch and spruce trees killed by the increased water level. Right: interpretation sign to tell visitors about the restoration work

Kauhaneva-Pohjankangas

Kauhaneva-Pohjankangas National Park is a complex of raised bogs and aapa mire (Figure 19). It is the most southerly aapa mire in Finland, and as such has high value for education and visitors. It is comparatively easily accessible from the major population centres compared to those father north and as a result has additional restoration value.

Figure 19. Aerial image of the aapa and raised mire complex at Kauhaneva-Pohjankangas

A golden eagle nests close to the mire and can sometimes be seen from the viewing tower erected by Metsähallitus (Figure 23). A fantastic network of boardwalks also stretch across the park (Figure 20), allowing visitors to see the aapa mire without getting their feet wet. Picnic areas have been set up at particularly scenic points and a swimming platform, complete with ladder, has been constructed in one of the peat lakes. In addition to the eagle the mire is also host to hen harriers, bean gooses, red throated loons, willow ptarmigans and wood sandpipers, all of which may be observed from the tower and boardwalks.

After taking in the beauty of the pristine mire we moved on to a restored area which had been drained in the 1960s. This is a special site as it is a natural 'spruce swamp', which are very rare now in Finland. The mineral-rich properties at this site are due to the upwelling of groundwater at the site and such springs are also very beautiful to observe. Since drainage, the peat surface subsided more than 1 meter as it dried out and started to oxidise. Restoration was carried out 2 years before my visit, and although the drainage at the site was commercially successful the timber has not been harvested as there is a rare beetle present at the site which the managers do not want to disturb. To limit the impact on the site ditches have not been filled in but peat dams have been periodically erected. These appear to be working well, with a large difference in water level between the two sides. Some ditches were dug so deep they started eroding down into the mineral soil below the peat (Figure 23). It was difficult to photograph some parts of the forest as the canopy was incredibly dense, blocking out the light and leading to the loss of many of the rare ground species (Figure 22). Nonetheless in the wetter parts of the forest swamp vegetation cover is still present and is starting to recover (Figure 22). Peatlands such as this, that are nutrient rich and have lost much of the original surface vegetation, are thought to be the largest emitters of soil carbon and should therefore be a high restoration priority, unfortunately their suitability for growing timber means this is often not the case. Quadrats, marked by the white pipes, have been set up to monitor vegetation recovery (Figure 22). Restoration has also filled the drains that have re-diverted water flow to the dried stream beds (Figure 21) and it is hoped that the aquatic species that once inhabited them will now return. The rare *Carex globularis* observed in the restored stream bed would suggest this is already occurring (Figure 23). Ditches are a poor substitute for natural streams as they are often deeper and faster flowing. In addition to this the water acidifies and the quality decreases as the peat decays in drained sites.

Figure 20. Walkways across pristine peatland enable easy access for visitors

Figure 21. Left: pristine groundwater spring. Right: artificial ditches than once diverted a stream are now blocked

Figure 22. Left: vegetation monitoring plots in restored forested peat swamp. Middle: restored stream flowing through forested swamp. Right: drained forested swamp with near total loss of peatland vegetation - peat surface is subsiding with roots appearing at the surface

Figure 23. Left: ditch has incised down to mineral substrate in a drained peatland. Middle: viewing tower enabling visitors to see the peatlands from above. Right: rare Carex globularis plant colonises a restored stream bed

After visiting the restored spruce swamp we moved to an area of the park where a groundwater spring was welling up among the peatland. Here the tree growth has not been so successful. This site was restored in 1998 with the original ditches blocked (Figure 21), allowing the stream to return to its old course. Rare *Carex globularis* plants have now returned to the area and can be found on the original stream bank (Figure 23). Although in this site dams had been erected periodically, it is better to fill the ditch in entirely as often in flood events the dams can breach.

The final site visited that day was a pristine mineral spring that had not been drained (Figure 21). This site was very beautiful and was home to many rare sedge, bryophyte and aquatic plant species that could be found around the edge of the spring. Very few of these sites remain and there is a strong case for restoring them for their biodiversity.

Lauhanvuori National Park

During my visit to Parkano a ‘reconnaissance’ was planned to find habitat suitable for the reintroduction of reindeer to the area as part of an EU life project proposal. The landscape at Lauhanvuori with its lakes, fens and lichen forests was deemed to be suitable, and if the EU funding is granted it is likely they will be reintroduced here. If that occurs the reindeer will be fenced in for a short time until they become accustomed to the area, then released to forage throughout the park.

Here at Lauhanvuori Pekka talked about some of dilemmas that come with restoration. A rare aquatic plant species has moved from the original stream, which was destroyed when the site was drained, and has taken up residence in the drainage ditches (Figure 25). One possible approach to this is to restore some flow to the original stream and to translocate the plant, or gradually raise the water level in the ditches and monitor the effect on the rare species.

Many areas cannot be easily accessed by machinery, and especially when there are rare and sensitive species present the disturbance caused by this is unacceptable. In this case dams have to be made by hand. Peat dams are labour intensive and plastic pilings are expensive. Here I saw the Finnish alternative, which is a plywood damn constructed using peat and timber from the site (Figure 24). These are relatively inexpensive and effective compared to other techniques. Note the raised water level on the right of the photograph. Interestingly some creature appears to like the taste of the plywood and has nibbled the end of the dam (bottom left Figure 24), though this has not caused a problem so far!

When planning dams such as this, it is important to consider what will happen to excess water during storm events. Thus the dam must be made higher than the ditch level and there should be a clear path for the water to travel along without damaging the dam.

Figure 24. Handmade dam using plywood and peat -note the difference in water level of either side

Figure 25. Ditch that cannot be filled due to rare aquatic plants that have taken residence. Water level can be gradually be raised with weirs to minimise the disturbance to the species

Figure 26.Clear groundwater spring in the middle of the peatland

Mires of Northern Europe conference 2015

The Mires of Northern Europe conference was held in Petrozavosk, in the Russian region of Kaerelia, a day's travel by train or car from Helsinki. Peatland science has a long established tradition in Russia, which is unsurprising as Russia contains more of the world's peatland than any other country. Finnish land managers and conservation officers also work closely with their Russian counterparts, as nature and hydrology do not respect national boundaries.

Much of the conference was dedicated to the diversity of European and Siberian mires, with delegates from Italy, Finland and Estonia as well as many of the Russian regions (Figure 28). The vast array of mire types and the inaccessibility of many mire regions means many new types and distinct vegetation communities are still being categorised.

In Russia it is possible to see rich fens of a type that has been drained out of existence in Finland (Figure 27). These areas have been kept treeless through a tradition of regular harvesting by hand of the sedge communities to feed to livestock. This has probably been occurring for thousands of years, but these mires are now under threat, as with modernisation sedge harvesting no longer occurs. During another talk it was mentioned that the rich fens of Bashkortostan are under quite the opposite threat. These are being overgrazed around towns and villages where horse breeding occurs, and the mires are gradually being lost.

One message I took home from the conference was the incredible diversity and extent of relatively 'wild land' still present in Russia, which may be rare or lost from the rest of Europe. Much of this diversity is informally or loosely protected and these areas are little known or visited by the rest of Europe, including by the scientific community. Russian peatland scientists are doing a great job, however the opportunities for study are enormous and little is known about the functioning of many Russian peatlands, some of which may be gone of forever altered by the time the chance comes for investigation. Many opportunities exist for collaborative projects, both scientific and conservation-based. UK peatland scientists, for example, tend to have very strong skills for studying the biogeochemical cycling of mires and interactions with climate. However these skills are often put to use studying small, often disturbed, peatlands which are of questionable global significance for either greenhouse gasses or biodiversity. It could be argued that these skills would be better spent on collaborative projects studying mires that are undoubtedly of global significance.

Central Russia is currently grappling with the consequences of peatland drainage, which has mostly occurred due to peat extraction. These sites periodically catch fire. This happened during the summers of 2010 and 2012, severely affecting air quality in Moscow. Extensive peatland restoration is being carried out in response, with the focus on damming large drainage canals and raising the water table. 67 105 hectares have been rewetted since the large fires of 2010, and the greatest practical obstacle to continuing restoration is the damage and breaching of the dams before the drainage canals become overgrown.

Figure 27. Visit to the eutrophic fens in Russian Karelia - this type of peatland has been drained out of existence in Finland

Figure 28. Peatlands of Northern Europe Symposium delegates, Petrozavodsk.

Salamajärvi National Park

After returning to Finland from the conference I went to visit the mires located around Viitasaari in mid-Finland, central Ostrobothnia. This park was a real highlight of the trip. There are over 70km of trails, and one of them lead me to the impressive Heikinjärvenneva mire, a complex of raised bog and appa mires.

Some of the oldest peatland restoration work in Finland has been carried out at Salamajärvi National Park. This is where Metsähallitus gained much of their early expertise through trial and error. Much of this early work was unsuccessful due to dams not being robust enough or high enough, and these sites have since been re-visited and filled with an excavator. This is well communicated throughout the site, with interpretation signs explaining the restoration work (Figure 30) and the wider Boreal peatlands life project (Figure 29).

At Salamajärvi it is possible to see some of the most Southerly aapa mires in Europe. Aapa mires are fens, meaning they are not exclusively rain-fed. They tend to be very wet, with more open water than a raised bog. A pattern of ridges and pools forms due along the path of water flow, making them quite beautiful to behold.

The very wet nature of aapa mires means draining them can be quite a challenge. Such sites have generally been avoided for tree planting, with only 3% of peatland forestry south of the 66th parallel situated on drained aapa mire (Eurola, AApala, Kokko, et al. 1991). However a larger proportion is influenced by regional drainage and we saw some of these sites that had been restored. The birch trees that has rapidly spread on the drained aapa mire were quickly killed off by the raised water table (Figure 31).

Figure 29. Interpretation sign on EU funding for peatland restoration

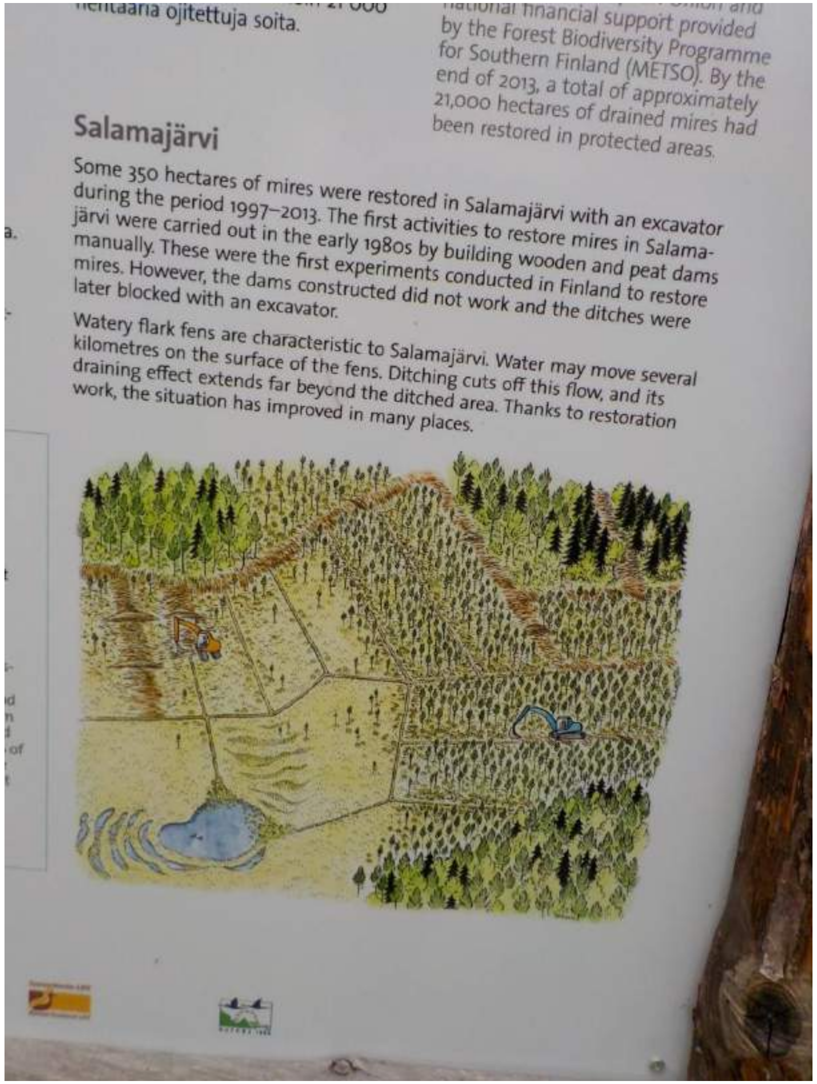

Figure 30. Interpretation sign describing the drainage of mires and the restoration work that has been carried out

Figure 31. Top, middle: dead birches killed by raised water table in restored aapa mire. Bottom: path through the mire, over 70 km of trails pass through the park

Pyha-hakki National Park

My final site to visit was Pyha-hakki National Park. This park contains the best-preserved old-growth forests in Southern Finland and more than 30km of trails. Pyha-hakki National Park is a perfect example of the natural mosaic of peatlands and old growth forest which once existed across much of Finland. Mineral islands of trees exist within the peatlands, these are much easier to burn as the danger of the fire spreading is much smaller. The fires prevent the ecological succession of spruces and birches, while providing dead wood for birds and rare invertebrates. After the fire the blueberry, *Vaccinium myrtillus*, or mustikka as it is known in Finland, grows with renewed vigour (Figure 33).

After visiting the mineral forest we proceeded to a site where restoration has failed. The site is dominated by a dense thicket of birches (Figure 34) that have sprung up after the pine cover was removed. This site has been abandoned for now, as birch is very difficult to kill off and must be felled multiple times before it eventually dies. Resources would be better spent restoring areas that are cheaper and more likely to succeed.

Figure 32. Sedge-dominated fen in the morning mist

Figure 33. Top: recovering vegetation in a burnt forest mineral island surrounded by peatland. Bottom: Sphagnum mosses and cloudberry (Rubus chaemorus) overgrowing pleurozium schreberi forest moss. Bottom:

Figure 34. An early restored site where pines were completely removed and birches rapidly grew to take their place - attempts to remove the birches cause the 'thicketing' effect seen here

Figure 35. Rare mesotrophic species Lycopodiella inundata – species such as these should be identified before restoration work is carried out, the disturbance carried out by ditch blocking and felling could potentially damage them

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Discussion

Prioritising restoration

It is important to first determine your needs and goals before planning peatland restoration. Sites can be chosen on the basis of benefits to biodiversity, carbon emissions or social value. Undoubtedly economics will also play a role in prioritising sites, and some restoration may have very specific goals, such as improving water quality or for flood prevention. Each land manager will have to determine the importance of these factors and work with the resources available to them. This section addresses some of the most common considerations a land manager will take into account when planning restoration.

One of the primary objectives of restoration is to prevent biodiversity loss by improving the quality of habitat for threatened species. As such peatlands that represent a particularly rare type or that are capable of providing habitat for endangered species should be top priority for restoration. The wider landscape should also be considered in such situations. For example runoff from drained peatlands is often damaging to aquatic ecosystems, thus restoration of sites is recommended where an improvement in long-term water quality is desired. However this must be weighed against the short-term disturbance and decrease in water quality caused by restoration efforts.

From a carbon-emissions perspective prioritising sites for restoration can be more complicated. Sites where peatland oxidation is highest also tend to be the most difficult to restore. The largest sources of peatland emissions tend to be in deeper, more fertile peatlands that have lost most of their original surface cover. Deep peatlands tend to be less economical with greater ongoing costs, such as ditch deepening and the measures to mitigate the increased windthrow risk. It may be that economic factors make these peatland types the most desirable for restoration, and they have the potential to emit larger amounts of carbon.

It is important that people, both visitors and locals, are considered in restoration projects, especially when large amounts of public money or that of charities is involved. It's strongly recommended that a plan is put in place to make some of the restored sites accessible, with boardwalks for example. Peatlands have in the past been seen as 'wastelands' of little value to society, and it is vital that this perception continues to alter if peatlands are to be protected. On a national, or European scale it may be advisable to prioritise the restoration of some sites within reach of large population centres, even if the value for carbon and biodiversity may be low.

Planning restoration

The most important part of restoration is hydrology. For this reason the blocking of free-draining ditches should be the first priority for any restoration scheme. Filling in ditches is desirable as dams can often breach in heavy weather events. If dams are used they must be constructed in a way that means they are stable in the long term and can be an effective barrier for up to 30 years, or however long it take for the ditch to fill naturally.

Ditch dams are usually constructed in late summer or autumn in Finland, these are left over the winter and are checked again after spring melt and any damage repaired. Any dam failures usually occur in the first season but dams should be periodically checked after particularly heavy rainfall. Other than periodic checking of the dams, sites are left for approximately 10 years before changes to the water level and tree growth are assessed. This will determine whether the restoration plan is working and if any tree felling or ditch blocking is required.

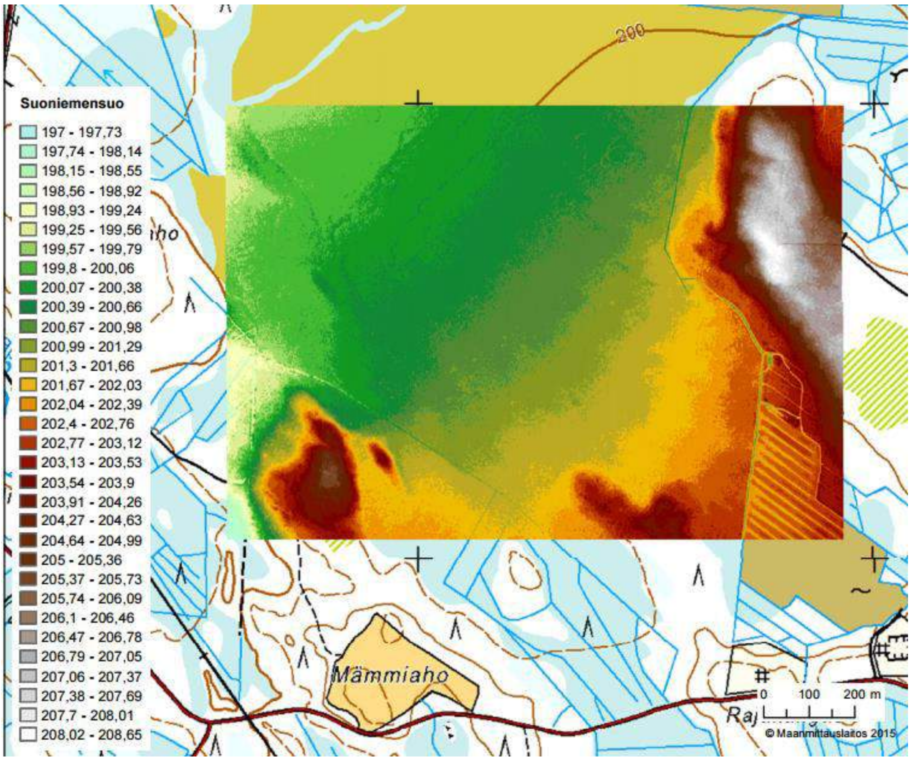

Figure 36. LIDAR used to measure surface elevation, this is very useful for determining which drains are effective and how future subsidence may affect water flow - photo courtesy of Reijo Hokkanen

Dams must be made higher than the ditch level, an overflow must be planned so the dam is not breached during heavy rainfall. A large part of restoration is constructing dams and blocking ditches in a way that will be effective for ten or fifteen years, or long enough for the ditch to fill naturally.

Challenges to restoration

Well-planned peatland restoration usually goes without a hitch, however there are a few things to watch out for. Issues that came up often on my visit included: dam breaches, invasion of willows, and damage to threatened species.

Fundamental to restoring a peatland is the restoration of its hydrology. This usually involves the blocking of ditches. Dams can act as weak points and must be checked and maintained until the ditch is filled. The risk of dam failure can be lessened by filling the entire ditch, though this is often more expensive. An alternative is allowing a channel for overflow which will not cause erosion of the dam. The ditches should be checked after exceptionally strong rainfall events or after snowmelt, and any maintenance work carried out as required.

Invasion of the restored site by birches is a common problem in Finland, especially for sites that have been fertilised. This can be avoided by limiting felling of pines on these sites and raising the water level as quickly as possible. Once birches become established it is very difficult to remove them from a site so it is best to prevent them from becoming established in the first place. Once birch trees have matured the increased evaporation they cause can negate the efforts of ditch filling and makes restoration very difficult.

In some circumstances restoration work can endanger existing cultural or natural features including rare or threatened species. This should be considered before work is started. Measures can be put in place to lessen the disturbance of restoration work, such as creating dams by hand rather than relying on an excavator. Any rare species that may be affected by the work should be monitored during the restoration process and steps taken to ensure any impact is negligible.

Advice from Finland

This section deals with the advice I received from the people I met on the study visit, it is mostly practical advice on the management of peatlands which I felt would be valuable to include in this report.

Bird conservation: if there is an endangered raptor nest close to a farmers land they are paid regardless of losses to stock. Many farmers were won around by this and now assist in the conservation and monitoring of these sites. The old method was to compensate for stock loss. This was an added complication and annoyance for the farmers as they were required to prove this was the case and was not an effective enough measure to win the support of farmers.

In Finland the mires are seen as an important part of national culture. They have economic value for the ordinary people who pick berries on them, and also great recreational value due to their inherent beauty and the wealth of rare wildlife they support. Metsähallitus do a really good job of making the peatlands accessible and helping people get the most out of them. All of the national parks I visited contained boardwalks and many also had picnic areas and even swimming platforms constructed out among the peat and peatlakes. If the restoration and protection of peatland ecosystems is to be funded by public money, I believe it is essential to make these areas accessible to members of the public and encourage their use. Concerns about the impact of visitors or boardwalks on the landscape must be weighed against the greater risk of alienating the public, and risks encouraging the misconception that peatlands are ‘wastelands’ in need of development.

Figure 37. Metsähallitus encouraging people to get outside and enjoy the peatlands

On my study visit I spoke with land managers about the prospects of timber from restored sites being used for bioenergy. Such wood is not usually suitable for bioenergy in Finland as tree felling is generally avoided if possible and when it does occur the wood is generally not of a quality suitable for bioenergy, the timber being too small and not energy dense enough. The timber is of more value for paper and pulp production.

The economics of using timber from restoration sites for bioenergy may be quite different elsewhere. In the north of Scotland, for example, the sawmill and pulp processing infrastructure simply does not exist, and the limited amount of timber, much of it low quality and slow growing, does not make the implementation of this infrastructure viable. Here there are perhaps opportunities for small scale and community heat and power projects, but it is also possible that the costs of harvesting and transporting this timber may outweigh the value of the heat and power produced. The economics of these schemes should be calculated and considered along with the greenhouse gas emission savings, the local employment opportunities, and the benefits tree removal may have on restored sites.

One of the restoration sites I visited required tree felling and this was carried out by volunteers from the local prison. The work was not too demanding and mostly involved the cutting down of smaller trees. The quality of the work was often variable, but considering it costs very little it is good value for money. Prisoners were very willing to volunteer their services as it is not too strenuous and provides a valuable and rare opportunity to spend time outdoors and in a natural environment.

The effects of peatland restoration on water quality can often be quite negative in the short term, and losses of phosphorus are a particular problem. It is very difficult to completely avoid these impacts, however they can be minimised by carrying the restoration work out over a longer period of time, or carrying out work at a time that is less likely to have a negative impact, for example in winter or spring when the river flows are highest.

Ideally monitoring of protected species should be carried out in watercourses downstream of the restoration site to ensure the works are not having a negative impact. In the longer term restoration can be expected to affect the water quality of runoff positively and has been shown in some circumstances to boost biodiversity in streams and rivers downstream.

Conclusions

Peatland forestry in the UK and Ireland is very different to that found in Finland or throughout much of continental Europe. The more intensive management used in the UK and Ireland for example the ploughing, planting and the use of exotic species will pose a unique challenge for restoration. In Finland it is rare that bog vegetation is totally lost from a site - when such sites occur they are considered to be the hardest to restore. In the UK and Ireland the near total loss of bog vegetation is the norm.

Nonetheless there are many lessons to be learned from restoration projects in Finland, as many of the basic ecological and economic principles are relevant to restored peatlands everywhere. The basic priority of restoration, before anything else, should be restoring the hydrology of the bog in such a way that does not have detrimental effects on rare and important species. If this can be done then the bog will eventually recover, nutrient inputs from trees and materials left on site are not important in the long term - if the hydrology can be restored the bog will eventually revert back to its natural nutrient state.

Sometimes the removal of trees is necessary in order to restore hydrological conditions by reducing the rate of evapotranspiration, but other cheaper techniques such as ringbarking can be employed. In the UK the removal of trees has also important to allow light to reach the bog surface.

Restoration should prioritise the damming and preferably the blocking of ditches. Caution should be applied when considering felling of trees, as invasion by birch and other opportunistic species is a common occurrence. Such problems may not be such an issue in Scotland and the UK in general, as conditions are not conducive to tree growth and high deer populations will help control tree growth on restored sites.

I would therefore recommend that the current research on peatland restoration takes into consideration leaving trees unfelled, as this is often a major expense for peatland restoration. If raising the water level proves to be insufficient for killing the trees then ringbarking could be employed , which is a comparatively small expense compared to felling. It may be the delays this causes in the establishment of bog species may be deemed unacceptable, as the restoration process would likely take much longer without felling. However if the establishment of species proves to not be too dissimilar to felled sites this may be a compromise worth making, especially if it enables a greater area to be restored for the same cost.

Restoration techniques that do not seek to restore hydrological conditions through ditch blocking and damming will likely fail and should be avoided. Utmost priority should be given to hydrological planning.

I believe peatland researchers in both Finland and the UK need to be better at disseminating their findings amongst site managers. Currently large restoration projects are being driven primarily by the well-established benefits to biodiversity, and carbon is given less consideration due to perceived uncertainties around this issue. The science around carbon emissions from planted peatlands is much stronger now than it was 5 or 10 years ago and the relative emissions from different site types are now much better understood. While precise emissions are still very much site specific, sites that are likely to be high peatland carbon emitters can be easily identified, such as nutrient rich sites with little or no remnant peat-forming vegetation.

Metsähallitus do an excellent job of communicating their work and opening up sites to the public. If restoration work is to be perceived as worthwhile by the ordinary people they cannot be excluded from reaping the benefits of it. I would recommend that boardwalks, viewing towers and picnic areas are included in restoration plans whenever possible and that every effort is made to make the peatlands accessible to people.

Historical damage to peatlands has been great. However, old attitudes are changing and there is now a will, which can be seen across countries, to protect and restore these ecosystems and reap the benefits accordingly. Effective communication between people involved with restoration can help ensure this is done in the quickest, most efficient and economical way.

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Glossary of terms

Peatland – a type of wetland where the rate of plant-matter accumulation is greater than the rate of decay, resulting in the formation of a highly organic substrate, peat.

Minerotrophic – fed by groundwater or overland flow, nutrients are received through these water inputs.

Ombrotrophic – exclusively rain-fed, most nutrients come from rainwater.

Bog – a peatland that is ombrotrophic, or exclusively rain-fed.

Fen – a peatland that is minerotrophic, or receives groundwater or overland flow.

Aapa mire – large fen complex, often with distinctive ridge hollow pattern.

Raised bog – a peatland that through vertical growth has become hydrologically isolated from its surroundings and has become ombrotrophic.

Oligotrophic – nutrient poor.

Mesotrophic – a moderate level of nutrients.

Eutrophic – nutrient rich.

Ecotone – the boundary between two ecosystems, for example mineral forest and peatland.

Spruce - refers to *Picea abies* or Norway Spruce, which is of less commercial value in Finland and grows naturally in the more nutrient-rich peatlands.

Pine – refers to *Pinus sylvestris* or Scot's Pine, the chief commercial species in Finland which grows naturally on many peatlands.

Sphagnum – the genus of main peat formers in the northern hemisphere, which are able to grow in very nutrient poor conditions and are highly resistant to decay.