RAMSAR CONVENTION ON WETLANDS
22nd Meeting of the Scientific and Technical Review Panel
Gland, Switzerland, 18 – 22 March 2019

STRP22 Doc.7.2

Draft Ramsar Technical Report on peatland restoration and rewetting methodologies in Northern bogs

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Foreword

Restoration of degraded peatlands is receiving increasing attention in different parts of the world. Restoration up to recently has mainly been implemented in order to restore biodiversity and ecological processes but increasingly attention is given to rewet carbon rich soil to mitigate climate change.

This Ramsar Technical Report provides information on restoration and rewetting methodologies in order to restore degraded peatlands, and is based on practical experience from various restoration projects in Northern bogs due to capacity constraints. The restoration of natural wet conditions including a high water table is for example often an essential part and thus the methods described here may very well be relevant in many other areas. However, it is suggested that one or more additional Ramsar reports can be considered for sharing restoration experiences for other regions and with other peatland types.

Moreover, peatlands differ widely in the way they are formed and in their physical, chemical structure and composition. The main focus in this report has been on the restoration of ombrotropic peatlands i.e. those receiving their nutrients from the air. It is believed that the practical field experiences presented here can be of inspiration also for other peatland types but again a similar collection of restoration experiences for other peatlands including e.g. fens is advice able.

The initiation of a process towards restoration of peatland habitat is certainly crucial for biodiversity conservation. However, for climate change mitigation rewetting is also an essential part as it is the high water table which prevents the net GHG emissions from degraded peatlands.

This report has been developed based on a request by Parties to the Ramsar Convention at the 11th Conference of the Parties in Uruguay 2015 (Resolution XII.11 Peatlands, climate change and wise use – implications for the Ramsar Convention) with the following content: *A Ramsar technical report providing an overview of restoration and re-wetting methodologies and in order to prevent carbon transfer from soils and vegetation to the atmosphere. The target audience is identified as primarily being wetland managers including Ramsar site managers*.

The narrow focus of this report is explained by the fact that the task not has been funded by the STRP funds available because it was not considered among the high priority tasks within the triennium 2015-18. Thus resources have been limited and the collection of examples and test cases limited to those who immediately responded on request of the authors.

What is a peatland?
Peat is defined as a sedentarily (in-situ) accumulated material comprising at least 30% (dry mass) of dead organic matter. A peatland is an area with or without vegetation with a naturally accumulated peat layer at the surface. Peat accumulates in areas of excess moisture where waterlogged conditions prevent the complete decomposition of dead plant material. In most natural ecosystems the production of plant material is counterbalanced by its decomposition by bacteria and fungi. In those wetlands where the water level is stable and near the surface, the dead plant remains do not fully decay but accumulate as peat. Where peat accumulation has continued for thousands of years, the land may be covered with layers of peat that are several or many meters thick. Active peat

forming peatlands (in some regions named mires) can be very variable in terms of their formation, hydrological regime, chemistry and plant communities:

There are two broad hydrological classes of peatland:

1. Ombrogenous mires (raised bogs) are typically water shedding systems, receiving their supporting water from rainfall. Restoration attempts often therefore try to prevent water from leaving a damaged bog system through re-wetting.

2. Minerogenous mires (fens and transition mires) are typically water receiving systems. They are connected to their surrounding landscape and receive water from a mix of locations including rainfall, groundwater, surface water and overland flow. Restoration may involve attempting to reconnect these peatlands to their landscape so that they receive sufficient water. Restoration may look to limit certain inputs due the damage they can have e.g. diverting nutrient rich run-off from agricultural land because fertilizer or pesticides would result in greater damage to the peatland habitat than the benefits from receiving that hydrological input.

As mentioned it is restoration experiences mainly under the bog type defined under point 1 above, which are presented here. It has been the purpose in the development of the report both to have a biodiversity and a climate perspective and preferably both at the same time. However, the definition of paludiculture probably does not necessarily include biodiversity but certainly it involves climate change mitigation.

Acknowledgement

We are extremely grateful to the individual contributors of the various chapters and also want to thank David Stroud (UK), Line Rochefort (CA), Stephan Glatzel (AU), Jari Ilmonen (FI), Jenny Lonnstad (SV), Gert Michael Steiner (AU) for giving extensive comments to an earlier version of the manuscript. Moreover, an earlier draft was presented and discussed at the STRP meeting in January 2018 in Gland. Finally, we are most grateful to the individuals facilitating photos for the report including Emma Goodyer and Sandrine Hugron.

Summary

Restoration of degraded peatlands has received increased attention in recent years. Firstly, for starting a process towards trying to restore hampered or lost biodiversity and ecological processes and then more recently for rewetting carbon rich soil in order to mitigate climate change due to the huge GHG emissions from drained organic soils. Both biodiversity conservation and climate change mitigation benefit generally massively from restoring a more natural hydrology.

Included in this report is information on practical restoration and rewetting methodologies based on

experiences from projects and activities carried out in Northern bogs. Different methods for restoring hydrology are outlined e.g. blocking of ditches using plates of different material or applied in different ways and under different conditions. The report is illustrated by a number of photos carrying documentation of just a very few of the many actions in the field and accompanied with an explanatory text.

The proceeding chapters are dealing with the combatting of regrowth (restoration due to human induced drained conditions in degraded bogs), a chapter on regrowth of natural bog vegetation including *Spaghnum* moss as well as a chapter on the use of paludiculture i.e. the growing of biomass on rewetted organic soils with an aim primarily to mitigate climate change. Links to examples of peatland restoration projects or active oriented restoration research is provided in annex 1.

The report is not meant to come up with any final conclusion but rather to share experiences on restoration practices. If a conclusion should be drawn it would be, that it is demonstrated in numerous projects that restoration of former hydrology (or alike) of degraded peatlands is possible and that the results both for biodiversity and climate change mitigation generally are large.

1. Introduction

Restoration of ecosystems is increasingly becoming an important tool for mitigating biodiversity loss and safeguarding ecosystem services including climate change mitigation. Peatland restoration involves measures designed to change ecosystems that have been impoverished, damaged or destroyed due to human activity, and also reverting them to a state similar to or as near to their natural state as possible, as well as initiate reestablishing of some of their ecological processes and functions.

One of the primary objectives of restoration is to improve the quality of species' habitats, thus contributing to slowing or halting the rate of biodiversity loss, and at the same time providing a continuous platform for future evolution. The advantages of preserving and restoring peatlands with regard to mitigating climate change is now also widely recognized in international climate and biodiversity policy-making spearheaded by the Ramsar Convention and also recognized by the Convention on Biological Diversity (CBD) and Climate Change Convention (UNFCCC).

Restoration and re-wetting methodologies are presented based on experiences in the field. It includes examples for inspiration. The report should help in answering questions such as *how should I restore my peatland* and *what methods should I use?* An important part of the report is illustrations in form of photos presenting restoration work in the field and thereby illustrating the different restoration and rewetting techniques used in practice.

The restoration examples in the report are just examples and the report do not intend to cover all aspects of a restoration project.

Restoration and re-wetting needs

A major factor causing peatland degradation is drainage introducing hydrological changes (including e.g. groundwater abstraction) in adjacent land. Pristine peatlands are still up to this day drained for agriculture, forestry and other uses including e.g. excavation of peat soil for horticulture and fuel. In the north the permafrost peatlands of the arctic and subarctic zone are hardly used. Here human impact is more or less restricted to hunting and gathering, Reindeer *Ranifer tarandus* grazing and infrastructure (roads, pipelines).

Many boreal peatlands are spontaneously forested though. Tree growth is, however, limited by waterlogging. Drainage removes this barrier and stimulates tree growth to allow for economically viable forestry. Re-wetting drained areas may restore ecosystem functions but full recovery of biodiversity and functions will be sometimes difficult. However, the initiation of a process of restoring wetland species habitats and wetland habitat types is important and will in any case enhance the functions and wetland services from the bog.

2. Preparatory work

The need for restoration and the prospects of success should be carefully planned and evaluated for each peatland site before a decision is made to proceed. As a basis for all peatland restoration work it is essential to understand both the ecosystems and the various impacts of drainage and restoration measures. In that regard the development of precise objectives for the restoration work is a vital part of a restoration project in order to steer the planning, implementation and impact monitoring phases of the project and to assess the efficiency of the restoration actions.

Identification of the type of peatland which are in front of you as well as a thorough knowledge of its (former) hydrology is crucial before embarkment on restoration activities. No two peatland areas are similar and any restoration project will be handled individually. Thus any project area and restoration case is unique. The solutions needed depend on a range of parameters. With this report of compiling best practices it is our wish that it easier to become inspired by the techniques and methodologies that best suites peatland restoration needs that you are facing in the field.

Before initiating a restoration project it will be necessary to set up preliminary investigations on e.g. hydrological and soil property as well as biological and more technical investigations such as topographical relevés. This report will not deal with such preliminary investigations in detail but it should be stressed that such preparatory work is indeed important.

Moreover, an important starting point will be preparatory studies related to land tenure and ownership. The ownership situation in your project area and the closest surroundings should be known. Both municipalities and the state should have easy access to relevant ownership data via cadastral maps, Geographic Information Systems (GIS) or a land register.

Three steps are important. A) Mapping the ownership structure so as to provide an overview of who owns what and identify the types of ownership involved. B) Clarification of the landowners' opinion of the concept of the project and C) clarification of the options and desire for land distribution, purchase/sale of land, land substitution and so on.

The majority of information on land owners can be obtained independently, but another option is to purchase a preparatory study including identifying ownerships. Whenever purchasing such a study however, it is recommended that you as project manager or alike participate in the questions and interview that probably makes up the core of such a study in many cases to ensure important continuity in relations with private landowners.

There are three important reasons to have a clear picture of the ownership situation: Firstly, in order to be able to inform owners and neighbors about a restoration project and its implications – preferably right from the concept stage. Secondly, in order to be able to evaluate the need for hydrological studies and thirdly in order to be able to evaluate whether there is a need, in connection with the project, for actually purchasing land, for land swaps or substitute land from a government pool. In other words landowners are crucial for successful implementation of any restoration project.

Furthermore, purchase of the necessary official permits etc. requires some planning and preparatory work. Early and ongoing contact with the relevant authorities is recommended. A good way to manage a satisfactory dialogue may be by the produce of a schedule and case plan to be processed by the authority together with the relevant municipalities.

A meticulous approach to filling in application forms, providing descriptions, map annexes, lists of landowners and so on in connection with applications makes the work of the authority easier. Be aware that meeting dates for political committees, obligations to consult involved parties, public hearings and announcements in weekly newspapers with long publication deadlines etc. can push back schedules.

Measures used in order to restore your peatland may influence a larger area including neighboring land thus it is important to know the hydrological implications of your planned project and to be consulting landowners.

Rationale

The restoration of wet peatlands allows the re-establishment or maintenance of biodiversity and important ecosystem services such as sequestration and carbon storage, water and nutrient retention, as well as local climate cooling and biodiversity conservation including securing habitats for rare species. Thus restoration is in line with the goals of several of the Multilateral environmental Agreements such as the Ramsar Convention, the Convention on Biological Diversity and the Climate Change Convention as well as regional and national priorities for mitigation environmental degradation and restoring ecosystem functions.

3. Restoration of peatland hydrology by blocking ditches

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Introduction

The most fundamental restoration need for degraded peatlands is to restore their hydrological functions and to restore a hydrological regime which is suitable / optimal for the habitat being restored. Optimised (stabilized) water levels are essential when restoring peatlands to ensure that the right conditions are created for peatland ecological function (e.g. to support climate mitigation outcomes) and for the support peatland biodiversity. Because hydrology often is dependent on a larger catchment a holistic approach will be necessary bearing in mind that just one leak in the hydrological system may cause its drainage.

In many cases, hydrology of a peatland will be impaired due to a previous attempt(s) to drain the site through the creation of artificial channels or structures. The purpose of the restoration will therefore be to reverse the effects of these drains:

- Drains remove water from the system- sometimes over considerable distances from the drainage channel itself. The purpose of the restoration intervention is to hold back water within the peatland or at least to slow down water loss from the site.

- Long-term drainage can lead to changes in soils structure. Physical losses of peat soil occur through oxidation and release of greenhouse gases or erosion causing soil to be washed from the surface. Subsidence and compaction of the soil may also occur. These physical effects cannot be immediately reversed but losses can be prevented while the restoring peatland recovers.

- Changes in vegetation occur due to water being less available in a drained site - either lowering water level or water moving more quickly through a site leading to fluctuating water levels and drier periods. Where drainage leads to the loss of peat- forming species, carbon sequestration may also cease.

- When drained peatlands are subject to oxidation of the organic soil due to lowering the water table there will be emission CO_2 and a cease of emission of methane. In nitrogen loaded peatlands, nitrogen oxide emissions can be expected as well depending on water level. By restoration the water table of bogs the balance of GHG emission will be in favour of reduction of total GHG emissions in the longer term and thereby climate change mitigation depending on the time perspective.

To reverse the above effects, drain blocking or the installation of dams in the drainage channel is a commonly employed methodology.

Blocking of ditches

The existing hydrology of a given peatland needs to be assessed before it can be altered. An imperfect understanding of the hydrology of a site can lead to poor hydrological control and, thus, wasteful use of scarce resources. Moreover, managers should understand the implications of drain blocking and how it might change water flows around the site including its potential exit from the site in a different place.

Sometimes blocking of ditches may be the last restoration action. In boreal peatlands, for example, the trees next to the ditches, first cleaned to get routes into the peatland with machinery, and then lastly blocked once the management work including reprofiling etc. is finished.

There are several considerations that need to be made in choosing a ditch blocking method. Drain gradient / slope and drain size are the two main factors that dictate the method used.

- Slope dictates spacing of drain blocks- infilling is also an option if material is available. Judging the correct spacing of dams is important to a scheme's success. Too few drain blocks and the restoration objective of re-wetting risk failure. Too many dams being installed would be waste of resources.

- Width and size of drain/canal dictates method used (engineering principles relating to pressure of volume of water behind dam and structural integrity). Longevity of materials used should relate to the amount of time it will take a blocked drainage channel to infill with vegetation and peat). The blocks/dams should be wide enough to prevent water moving around the dam. Peat dams should initially be higher than the peatland surface to prevent further leakage when the peat in the dams subsides.

Other considerations in designing a drain blocking scheme include:

- The condition of drain base. Questions to be asked includes if water is of sufficient quality and quantity available for the restored mire, depending on the need of the peatland in question as well as implement of water management depending on the drainage basin, if e.g. direction of surface flow into the peatland has been disturbed?

- In circumstances where a hard engineered dam has been put in place, water still requires an exit over the barrier to prevent additional erosion, so a shallow spillway or weir should be included within its design.

- Accessibility - how can you transport materials to each of the locations requiring a drain block? Are materials available locally e.g. peat, wood or stone? Or do virgin/newly manufactured materials, such as plastic, need to be purchased and brought onto site?

- Does the dam need to be completely impermeable or is the objective just to slow the flow of water? Some materials allow a drain to be quickly blocked using available material and, over time, will become more effective at holding back water e.g. a stone dam will hold back some water initially but the gaps between the stones gradually fill up and catch eroding peat soil. As the peat fills the gap, the dam can hold more water.

- Topography of the site surrounding the drains to be blocked. Is there any artificially low area around the drains that could prevent an even distribution of water, e.g. a path or a quad bike trail? If so, it should also be blocked.

Figure 3.1

Aerial view of blocked 'grips' or upland drains in blanket bog habitat, Yorkshire. The regular, rectangular shaped pools are visible as a result of peat dams being constructed across the ditch to form a hydrological barrier and maintain water within the peatland.

In between the peat dams, the drainage channel will hold water (visible as darker rectangles). These pools initially form important habitat for aquatic peatland species such as *Sphagnum cuspidatum* and invertebrates such as dragonfly. As the pools gradually terrestrialise and infill with vegetation, the chain of rectangular pools will become less visible.

Figure 3.2.

Example from Canada of artificially low areas that needs to be taken into consideration as they are located near a drain that will be blocked. If those features are not also blocked during rewetting actions, water will spread along the trails instead of being redistributed evenly.

Photo ©Line Rochefort, Grande plée Bleue peatland, Canada. 2012.

[original photo better]

Blocking ditches is an important instrument to slow down or stop the draining effect of the ditches on a bog. For blocking ditches several methods are available.

Peat

Smaller ditches with a width of up to approximately 2 meters can usually be quite safely blocked using naturally occurring peat. However, peat can also be used successfully for damming larger ditches with a low water column pressure. The peat must be well humified so that it is sufficiently impermeable. However, on sloping ground, peat dams in 2 m width ditches would likely fail and there might be a need to use other materials together with peat to ditch block anything over 1m width.

Depending on the needs and finances machinery can be used, however, for small areas or in areas with little funds, the use of machinery may be limited and some measures can be done manually. Peat dams must be constructed using a low pressure excavator or carried out manually in some areas depending on the specific conditions. Machinery will cause damage to the peatland if it is too heavy and manual work will in such cases be a preferred option. The drain spacing, i.e. the intensity of the ditch blocking very much depends on the hydrological assessment of the site, objectives, risks to surrounding land and materials available.

Figure 3.3. Building of a peat dams in Melnais Lake Mire, Latvia. Large but low pressure excavators is used in some cases such as here with a total weight of 3-7 tons or maximum 10 tons. Wide peat dam is built on the cross-section of 2 perpendicular dams. Portable steel plates are used to traverse areas of wet deep peat to reduce the damage of the excavator on the peat bog. Raising of water level was immediate

Photo © Mara Pakalne, Melnais Lake Mire Nature Reserve, Latvia. 2012.

Figure 3.4. Blocking of drainage ditches by peat soil in a degraded peatland. Each blocking is placed for every 10 cm decrease in slope. Pure well-humified peat from the area reachable by the excavator is compressed across the ditch and keyed into both sides of the ditch. In this example peat blocking is used for a 2 meter wide ditch. In areas with a higher slope ditch blocking with peat only is not used if the width of the ditch exceed 1 meter. In such cases other material in combination with peat is needed. Wood could also have been used.

Photo © Leif Lyngsø, Store Okssø, Denmark. 2008.

Before building of dams, the sides and bottom of the ditch is cleaned by the excavator to remove vegetation and to ensure a peat-to-peat contact. Vegetation is kept for revegetation after the operation. Pure well-humified peat (see also the use of wood in a later section) from the area reachable from the excavator is then compressed across the ditch and keyed into both sides of the ditch. The operation is closed with covering the compressed peat blocking with the left-over vegetation. The length of the peat blocking must be long enough to avoid the water bypassing the blocking and returning back in the downward ditch, slowly causing peat erosion. It should be high enough (at least 0.5 meter higher than the surrounding ground) to allow settlement of the peat. A 2 meter wide ditch will need a blocking of 2-3 meter width and 3-4 meters in length.

Figure 3.5. Freshly built peat dam. Building of a peat dam is carried out by the excavator, taking the wet peat from the area near the ditch. Dam is built high enough not to have water overlflow and wider than the width of the ditch. The operation is closed with covering the compressed peat blocking with the left-over vegetation.

Photo ©Mara Pakalne, Rozu Mire Nature Reserve, Latvia. 2012.

Figure 3.6. Example of a small blocking perpendicular to a large dam. To prevent overflow runoff and risk of erosion damage to the blocking a crescent-shaped shallow channel is created at the lower side of the ditch to allow the water to seep into the bog or to control the outflow when water level is high. It is often necessary to cover the run-off channel by a rubber or woven sheet to prevent erosion

Photo © Peter Hahn, Danish Nature Agency. 2016

Blocking ditches with natural occurring peat is a cheap and quick method. A machine operator with high level of expertise in working in bog environments can perform a number of drain blocks per hour when drains are small and close together. Experiences from Scandinavian projects are that by working in highly water saturated and excavated peat often underestimates how much the peat blocking settles subsequently. Additionally, wear and tear from wildlife or domestic animals can be significant because wildlife often choose the blockings when crossing the bog.

Plates (wood, plastic)

Another way of blocking smaller ditches is by using plates of wood or plastic for piling. However, in large bog areas the transport of large and heavy plates will often be difficult and more expensive than peat blockings.

The longevity of wooden dams can be a concern, because the dams become leaky over time. However, since the wooden dams often are used as blockings in smaller ditches and the ditches over time will be blocked due to natural sedimentation and re-filling, the decomposition of the wooden dam is in many cases not a problem.

Plywood plates are often produced in standard sizes limiting the size of the ditch that can be blocked by one plate. In wider ditches more plates can be assembled with screws and connecting pieces. Another solution is to build a customized-size plate by assembling wood planks – ideally larch or cedar that will be resistant to decomposition.

To block a ditch with plates, the same dimensions are necessary as for peat blockings. As preparation, roots are cut with a pit pincer. Hereafter the plate is piled down with the excavator shovel. A strong U-shaped iron profile was laid on top of the plate to protect the plate from damage during the down-piling. It is important to avoid damages to the wooden plates, as a frayed edge will degrade quickly. For the same reason the plates should preferably be without grooves and ridges.

Figure 3.7. Placement of plywood plates in a ditch in. To block a ditch with plates the same dimensions are necessary as for peat blockings. As preparation roots are cut with a pit pincer. Hereafter the plate is piled down with the excavator shovel.

Photo © Leif Lyngsø, Store Okssø, Denmark. 2008

Figure 3.8. Plywood plate in a ditch. It is important to avoid damages to the wooden plates, as a frayed edge will degrade quickly. For the same reason the plates has to be without grooves and ridges and should be covered with peat at both sides to prevent degradation of the plates. Thus after the wooden plate has been placed across the and keyed into both sides of the ditch it is covered with peat

Photo © Leif Lyngsø, Store Økssø, Denmark. 2005

Figure 3.9. Three years old blocking. The top of the wooden plate is just visible at the surface due to degradation of the overlying peat. But soon the overgrowth with bog vegetation will cover the plate.

Photo © Leif Lyngsø, Store Økssø, Denmark. 2008

Figure 3.10. A peat filled wood cribbing can be added upstream in cases where high water pressure is anticipated. The wooden structure should be covered with peat and ideally revegetated to reduce erosion.

Photo © Marie-Claire LeBlanc, Canada, 2011.

Figure 3.11. Another example of wood dams in Sudas-Zviedru Mire, Latvia, built in 2017.

Photo © Mara Pakalne, Sudas-Zviedru Mire. 2017

Figure 3.12. Plastic plates are well suited for less accessible places because of their low weight compared to other material. Plastic plates are often produced in various sizes and can easily be cut into proper length or if the plate encounters roots shaped accordingly. Figures here show examples of installation of plastic plates as a blocking of a large ditch in a bog. As for wooden plates it is important to cover the plastic plates with peat to prevent degradation of the plastic from the UV light (not done here). It is also important to build up compressed, well-humified peat on both sides of the plastic plates to prevent water to seep through the junctions.

Plates of waterproof plywood can be used where access to and transport in the bog isn't a problem, while plastic plates are used in areas where transport is impossible or where the vegetation is too vulnerable the pressure from heavy equipment.

Figure 3.13. Another much more expensive solution is to transport the heavy wooden structure by helicopter, which in this case was proved to be a relatively cost-efficient method in this remote nature reserve.

Photo © . PERG (Peatland Ecology Research Group), Grande plée Bleue Peatland, Canada 2011.

Figure 3.14

Wooden dams form a useful way to prevent water and sediment loss in deep erosion gullies, like this one in the Pennines (England). The broad notches cut in the top of the dams allow water to gently spill over into the next section of the channel. The construction with horizontal wooden boards, pinned between posts, makes for a strong consruction that can withstand a build-up of water pressure behind the dam. The boards also allow for a slight leakage to occur which prevents the water building up too quickly and causing the dam to fail.

This particular piece of peatland restoration was being undertaken by a volunteer workforce, co-ordinated by one of the peatland partnership groups in the UK. The vehicle that can be seen in the top of the photo is a low ground pressure 'Softtrak' that allows materials to be brought onto the site without causing damage to the peatland along the access route.

Sheet piles (iron)

Sheet piling can be a positive technique if for example nutrient flows from external areas are a concern, but needs careful consideration if there is a risk of permanently isolating the peatland unit from its surrounding landscape and supporting hydrological connections.

Sheet piles of iron can generally be considered in ditches/canals broader than 2 meters where water flow needs to be stopped. To make sure the water doesn't flow under the piles location of the solid ground is needed preliminary to the installation of the sheet piles. The sheet piles are vibrated down with a vibrator mounted on an excavator (see figure 2.15) and each pile is locked into the next pile by an interlock system. To control that the interlocks fits together and for safety reasons during installation a dam of peat is a good idea to establish next to where the sheet piles are installed. The dam gives a stable working platform for the crew and makes it easier to vibrate the sheet piles down. The dam also ensures a blocking of the canal when the iron sheet piles over time corrode away. How fast the sheet piles will corrode depends on the acidity of the water.

Figure 3.15. Sheet piles of iron are used to stop water in large ditches/canals. The sheet piles are vibrated down with a vibrator mounted on an excavator and each pile is locked into the next pile by an interlock system. To control that the interlocks fits together and for safety reasons during installation a dam of peat is established next to where the sheet piles are installed. The dam gives a stable working platform for the crew and makes it easier to vibrate the sheet piles down. The dam also ensures a blocking of the canal when the iron sheet piles over time corrode away.

Photo © Martin Nissen Nørgård, Portlandmosen, Denmark. 2010

Figure 3.16. Iron sheet piles are used when water needs to be dammed up over a long stretch. To protect the iron piles a plastic coverage is covering the top. This coverage can also be used as walking path when inspecting the iron sheet piles.

Photo © Martin Nissen Nørgård, Portlandmosen, Denmark. 2010

Cell bunding

Cell bunding is a relatively new, experimental technique which has been used with some success on lowland raised bogs in the UK. In raised bogs where the lag fen habitat connection has been lost and the edge of the peat dome has been damaged through domestic cutting of peat for fuel, it can be difficult to rewet the edges of the peat mass through drain blocking alone. Without re-wetting, the edges of the site it will continue to degrade and suffer from subsidence and scrub encroachment.

Cell bunding is developed as a technique to slow the surface and subsurface water loss from the bog and to retain as much water as possible on the site. Each bund acts as a wall to hold a shallow layer of water. Water is held in the cell by the creation of an almost impermeable wall of humified ombrotrophic peat. The water level is dictated by the height of the bund. Bunds should be topped with peat turves to prevent desiccation and erosion of the cell walls. Like peat dams, bunds are built approximately 50 cm high to allow for settlement (typically of 20-25cm). Cell size is important: smaller cells require more work to install a greater length of bunds but they break up the area of standing water and prevent wave erosion from damaging the bunds. Water held at the level of the peat surface helps to create the conditions needed for peat bog vegetation to colonise and the process of terrestrialisation to begin.

Sites where cell bunding has successfully recovered water table levels near the edge of the raised bog systems in the UK have managed to preserve water levels within the centre of the peat dome. Vegetation colonization typically takes place within the first 2-5 years and *Sphagnum* and cotton grass *Eriophorum sp.* are quick to dominate the restored areas.

Box for method:

- Dig a trench by removing 10-20 cm wide turf.
- Degraded peat and tree roots removed.
- Dig down a further metre into good ‘clay like’ ombrotrophic peat. Turn this peat over and squash back into trench – this blocks all cracks/fissures as well as cutting through roots.
- Create a borrow pit on the uphill side, remove turf and degraded peat then extract ‘clay like peat and use this to fill the trench to ground level and then raise to appropriate height.
- Cover ‘clay like’ peat mound with turf.

- Any tree roots, degraded peat placed into borrow pit and covered with turf.

Blocking/disconnection of drain pipes

Many bogs have been cultivated and drained for agricultural purposes. To ensure that raising the water level in a bog or peatland is not bypassed by still functional old drainpipes, it can be necessary to find and disconnect the drainpipes before a restoration project. Older maps of drained systems are very useful to point out where the excavator should dig. If no maps are available, systematic changes in the vegetation might reveal an underlying drainage system.

In situations where disconnection of drainpipes is needed, a backhoe digs a trench across the draining system and removes a couple of meters of drainpipes. Peat can afterwards be compressed in the trench.

Membranes

Dikes and dams can be necessary to establish along edges of an intact bog to prevent the bog from desiccation or in other places where water is needed to be kept inside or outside a certain area. Iron sheet piles will be too expensive to use in such situations, while membranes of either plastic or bentonite are cheaper and more manageable.

Plastic (Polymer)

Polymer membranes are delivered in long rolls. To prevent water seeping under the membrane, a preliminary location of the solid ground is needed to make sure that the membrane afterwards is installed deep enough.

The membranes are often installed in a continuous length to avoid the risk of leaks and are typically run along the wall of a dug trench and backfilled with excavated soil. As with the installation of drain blocks, the membrane may extend slightly above the soil surface within a soil bund. Membranes are a useful technique for both the maintenance of water levels within a site or for the exclusion of water from surrounding land. For example, they have been used at Cors Erddreiniog fen restoration sites in Wales (UK) to prevent nutrient rich water from surrounding farmland from entering a calcareous, poor-fen restoration site. The installation of the membrane was key to preserving the low nutrient conditions within the restoration site and allowing nutrient poor fen species to re-establish.

Fig. 3.17. Polymer (PE) membranes are delivered in long rolls. In some Scandinavian restoration project a special metal box has been designed to handle the polymer membrane roll during installation. The polymer roll is placed inside the box like a roll of toilet paper. The box is connected to a backhoe with a chain. The procedure is as follows: A. The backhoe digs a trench in the depth needed. B. The backhoe then drags the metal box inside the trench leaving the polymer membrane in the trench. C. The trench is closed and the peat is compressed around the membrane on the other side.

Photo © Jacob Palsgaard Andersen, Lille Vildmose, Denmark. 2012.

Bentonite

Bentonite is a type of clay having the characteristics of cohesion, binding, sealing, and thickening when it gets in touch with water. A bentonite membrane consists of clay granules between two layers of geotextile polypropylene fabric, one woven and one nonwoven, needle punched and heat fused together. The bentonite membrane has been used to make dikes waterproof.

Peat is removed when preparing the inner side of the dike (the edge of the bog) is replaced on top of the gravel for a more natural finish. Since the outside peat layer isn't in touch with water it will degrade continuously and new peat has to be added at a later time.

Figure 3.18. The same special designed metal box used for polymer membranes can be used to control the bentonite membrane when installed in a dike. The edge of the dike is prepared and roots are removed to make sure no holes are cut in the membrane. No more than 5-10 meters of bentonite membrane is rolled out along the new dike at a time in order to control the membrane in the right place. Gravel is placed on the outer side of the membrane to hold it in place. Otherwise the high pressure of water building up on the inner side of the dike might cause a collapse of the dike.

Photo © Peter Hahn, Tofte Mose, Denmark. 2015.

Figure 3.19. This is an example of a 1.7 km long and 3-4 meters high dike along an intact raised bog. A bentonite membrane kept in place by 14 m^3 of gravel per running meter and covered with peat. The result of the dike is an immediate holding back of water on the bog side of the dike. The trees on the bog will over time drown and die out and bog vegetation will spread out into the open water starting to recover the bog.

To slow down the flow of water along dike, a low blocking made of peat is built in perpendicular to the dike for every 10 cm of lowering in altitude. See figure 2.6.

Photo © Peter Hahn, Lille Vildmose, Denmark. 2016.

Figure 3.20

Cell bunding as a technique to attempt to hold water on a previously milled peat extraction site. Differing ground levels and remaining peat depths at this site make it difficult to achieve sufficient re-wetting through ditch blocking alone and so cell bunding is being trialled as a technique to hold water across a greater surface area of the site. In time, these pools within the cells have been shown to terrestrialise and infill with peatland vegetation. This process tends to be more rapid/successful if the surface water is not too deep (c. <30cm) and the size of the cells are not so large that wave erosion at the edges becomes an issue.

Restoration of severely eroding peatlands can be a daunting process but, if suitable conditions are successfully restored, visual recovery can be rapid.

Photo 2.20 is of a large eroded gully in the South Pennines (England) immediately after restoration measured were taken to begin blocking the base of the gully: newly installed stone dams can be seen in the gully bottom and are already beginning to hold water. The spaces between the stones will eventually block up with peat sediment and the dam will begin to hold more water.

Five years following the installation of the stone dams (and measures to re-introduce peatland vegetation to stabilise the bare peat surface), improvements in the site can be seen. The gully is beginning to infill and there are no longer large areas of bare, eroding peat. The small bare areas of peat which can still be seen on the steepest of the gully slopes will eventually infill with vegetation.

Photo © Moors for the Future Partnership, Pennines, England (before photo 2010, after photo 2015)

4. Removal of invasive vegetation

Contributors: Peter Hahn (DK), Emma Goodyer (UK), Edgar Karofeld (EE).

Introduction

Some peatlands are naturally forested, while others such as raised bogs are more or less treeless. A side effect of drainage is the often rapid overgrowth of the bog habitat with trees and shrub, which the natural high water table mitigates or prevents.

The following factors have a significant influence on the decisions whether a specific area should be cleared for trees and shrub as well as the choice of method.

- Growing stock of trees and shrub
- Hydrology (when is it possible to move around in the area) and what are the implications for water quality when clearing is undertaken
- Logistics (distance of travel, market for timber/wood chips for biomass to get the woody material off the site, etc.)
- Flora and fauna (including timing of restoration works in relation to breeding seasons etc.)
- Size of the area
- Technical solutions in terms of manual removal or the use of machinery etc.

Clearance of trees and shrubs

There are many peatlands which naturally support tree-cover such as the fen-carr woodland surrounding intact raised bogs or peat swamp forest in the tropics. However, in some instances the presence of trees on peatlands is not a natural situation and is due to either the direct planting of forestry on peatland or the intrusion of trees onto a dry and damaged peatland. In these circumstances, it may be appropriate to consider clearing the trees to support restoration or conservation activities.

Clearance of trees in peatlands serves two purposes. First of all, it provides more light to the ground surface to allow ground cover vegetation (e.g. *Sphagnum* mosses) to grow. Water is lost by evapotranspiration from the trees and, as the tree canopies develop and close, water is further prevented from reaching the bog surface by interception. This can reduce the amount of water reaching the bog surface by as much as 40%. In addition, the weight of the trees and the loss of water from the peat cause the peat surface to subside with consequent hydrological effects on adjacent areas of peat bog as well as on the properties of the peat beneath the plantation itself. Shading from the trees and needle fall may have a negative impact on the peat-forming *Sphagnum* mosses, potentially further inhibiting peat formation.

Restoration of afforested/ planted peatlands

The restoration of afforested peatlands is a developing field and a number of methods have been trialled:

- Scrub clearance
  Hand clearance through hand pulling is an effective method to clear small seedlings. The seedlings can be left on site provided that the roots are left to dry out and desiccate so that the seedling cannot re-establish.

  Brush cutters (lighter scrub) and chainsaws (thicker stems) can be used to manually clear more established scrub. Cut stems as low as possible to allow surface ground wetness and growth of *Sphagnum* to rapidly inhibit any regrowth from the stump.

  Spraying with an herbicide such as glyphosate can be used to prevent regeneration in continuous stands of scrub.

  Raising the water table will help to prevent re-growth of trees after scrub has been cleared. If hydrology is not adequately addressed, then subsequent management of scrub encroachment may be necessary.

- Ground smoothing/surface smoothing
  This aims to remove the plough throws and ditches within a planted forestry plantation. Tracked machines used to fell the forest are encouraged to fill material into the low lying ditches and track the machinery across the line of the ditch, compressing the material and the higher ground of the plough throws. This acts to even out the topography and brings more of the ground surface in contact with the water table.

- Stump flipping
  Dig out old, cut tree stumps with an excavator, flip upside down and push them firmly into the peat. Compact using the excavator bucket. Use the tracks of the vehicle to smooth the ground surface (as above).

- Mulching woody debris.
  Where possible, wood material should be harvested and removed from the site as soon possible. In some sites, ground wetness, local markets and availability of suitable harvesting machinery means that material has to be left on site. Some sites have successfully mulched the woody material and spread this across the site. Small trees/re-growth, cut tree stumps and brash material can be mulched in situ. Combined with re-wetting, peatland vegetation is able to colonise and grow on the woodchip surface when the correct hydrology is reinstated.

Mechanical clearance

Mechanical clearance with larger machines can hardly be recommended, however there are successful examples of using low-ground-pressure machinery in the UK. In another example an experiment on 0.5 ha Danish bog revealed a very time-consuming result compared to clearing by hand (chainsaw), a high risk of leaving areas of bare peat exposed to a following increased germination of birch seeds and need for a re-clearance by hand afterwards because the clearance equipment couldn't handle tree trunks thinner than 10 cm in diameter.

Figure 4.1

Where regeneration of forestry or self-seeded trees need to be removed from a peatland, there are several methods to consider which take into account site access, cost, contractor skills and desired end-point for ongoing site management.

In this example, conifer regeneration from forestry plantations are being removed by hand using a chainsaw to fell and section the small trees whilst they are still a manageable size. On this site, hand felling was considered to be a viable method as the density of regeneration to be removed was low and trees were still of a size which was manageable to be processed on the spot.

Photo © RSPB, Lake Vyrnwy, Wales. 2008

Manual clearance

Regrowth occurs not from the impact surface but from dormant buds below or just above the soil surface. It is therefore important to cut the tree below the surface to reduce the regrowth from dormant buds. Using chainsaw or brushcutter is possible. Both are able to cut into the peat without getting damaged, but the working position may complicate the work. In countries such as e.g. Russia, Scandinavia and Canada it can be done more easily in the winter when soil is frozen.

Figure 4.2. Light axes with a long shaft has shown to be the best choise for manual clearance. It is important to remove the brushwood right after the first clearance. Otherwise, the brushwood will complicate the access to the area under the next clearance. Furthermore, the brushwood will prevent the game from eating the regrowth.

Photo © Leif Lyngsø, Store Økssø, Denmark. 2010.

Combating regrowth

Drowning

Older birch stands in bogs often have a large and horizontal oriented root system because of the high water level. It is the access to oxygen in the soil that determines the development of the root system. An effective but slow method to kill the trees is to raise the water level. However, be aware not to flood the site and thereby increase methane emissions (a strong GHG gas). A permanent high water level will drown the trees within 2-5 years.

If the old birch trees cut down before the water level is raised, there is a risk the new upcoming birch (regrowth) reacts as young trees, that are significantly more difficult to drown.

Figure 4.3. Rewetted large ditch (8 m wide and 3 m deep) 3 years after restoration.

Photo © Sandrine Hugron, Grande plée Bleue Peatland, Eastern Canada. 2015

Cutting (high level stumps, starvation, crushing, etc.)

Experiments with cutting birch 1 meter above ground (in one case in July) were tried hoping for a quick desiccation of the trees. The results were that the high level stumps created at least as many new shoots as with a normal cutting, and made the access in the area more difficult.

A Danish attempt to starve the birch with a double clearance per year two years in a row has shown to be quite effective. The clearance took place from May to June and again from July to August and repeated the following year. The double clearance was followed by raising the water level to keep the regrowth to a minimum.

Grazing

After the first cutting the following year is dominated by regrowth from the old stumps and younger trees. A couple of years later germination of new seed plants can be massive with 50-100 plants per square meter. Seed banks from nearby solitary trees can be a challenge and removal of these trees can reduce the risk of seed production. With a massive regrowth from germinating seeds, manual clearance will be very expensive and time consuming and grazing may thus address this problem.

Goats are very effective – especially to combat birch regrowth. Compared to manual clearance with a brush cutter, goats are more selective and leave the special bog flora out. A brush cutter cuts all the vegetation down to the same level.

Grazing by goats can be used to clear an area for a short period as well as a following effort to combat seed germination. It is important that the grazing doesn't become a permanent management of a bog. Otherwise there is a risk of a permanent damage to the original bog vegetation.

Figure 4.4. Domestic goats are effective grazers because they prefer woody plants to herbs and grass. In larger very wet areas Moose can be just as effective or even more effective because the majority of their food choice is birch and willow. However, Moose generally requires a large area.

Photo © Leif Lyngsø, Store Økssø, Denmark. 2008.

Figure 4.5 In some parts of the UK e.g. Northumberland, Wales, and throughout Scotland, commercial forestry was planted on areas of peatland. In the period post world war 2, UK government incentivised the drainage and agricultural development of large areas of peatland: forestry was just one of the land use changes that was incentivised. In the Flow Country, government tax breaks in the 1970s and 80s led to large areas of blanket bog being planted with Sitka and Lodgepole pine. Current government policy no longer supports the planting of forestry on deep peat (>50cm) and there is beginning to be restoration funding available to restore these afforested areas back to peatland.

In this particular example at Forsinard in the far north-east of Scotland, forestry felling began in the 1990s. At this time, the plantation was not considered to be economically viable to harvest and so was 'felled-to-waste' with all of the tree material (stem and branches) being left on site. Whilst this removes the interception and evapotranspirative effect of the growing trees, it did not repair the ground level hydrology of the peatland. Drainage ditches remained and the plough throws and furrows arising from planting the rows of trees also acted to have an additional drainage effect.

The Royal Society for the Protection of Birds (RSPB), who manage this site, have now gone back into these fell-to-waste areas for a second phase of management to re-wet the site. The drains and furrows have been blocked with peat dams and any remaining tree material has been crushed into the peat soil. This photo was taken 3 years post re-wetting (c. 2013) and some areas of water at the peat surface can be seen in the foreground and right of the photo.

The RSPB reserve at Forsinard is large and work is phased: this allows for applications to different funding sources, helps to manage contractor availability and to mitigate for any adjacent environmental concerns e.g. the potential for peat sediment to run-off the site and cause damage to salmon spawning grounds. Due to this phased approach, some recent felling is visible top left and some standing forestry plantations are also visible in the distance (top-left).

5. Reintroduction of peatland vegetation

Contributors: Sandrine Hugron (CA), Edgar Karofeld (EE), Emma Goodyer (UK), Peter Hahn (DK).

Introduction

Introducing diversity or restoring non-*Sphagnum* dominated peatlands

Canada has been a lead on the reintroduction of native *Sphagnum* species and examples in this chapter are to a large extent based on Canadian experiences. Other countries especially in Europe have followed the experiences from Canada. Different methods exist:

- Plug planting: Peatland plants can be propagated and grown to order, and planted out in suitable locations by hand.

- Seeding: Donor material collected from other nearby peatland sites can be mulched and spread on the restoration area as a brash material. The material will contain seeds (e.g. *Calluna vulgaris*) which will establish within the restoration site.

- Erosion protection of bare soils to allow vegetation to establish (mulch material e.g. woodchip/straw material) or manufactured material e.g. coir netting/Geojute.

Sometimes to support the re-introduction of *Sphagnum*, a nurse crop will be planted. This is typical in sites which have large expanses of bare peat such as cut-over peatlands or eroding peatlands. The nurse crop quickly establishes and the roots help to bind the surface of the peat preventing erosion. These plants also help to provide some physical shelter to newly establishing mosses. Typical nurse crops planted in the UK include Cotton Grass (*Eriophorum* sp.).

Re-introduction of *Sphagnum species*

Peatlands such as active raised bogs are characterized by the dominance of different *Sphagnum* species. These moss species are able to soak high amounts of water and together with their ability to acidify the surroundings they create conditions where dead plant material over time is building up as peat. Partly decomposed *Sphagnum* fibers usually form bulk of the peat deposit of raised bog and *Sphagnum* species are therefore a fundamental part of an active raised bog.

When trying to restore, for example raised bog species, restoring or optimizing the hydrology is one of the prime efforts (as described earlier) and is essential to prevent further degradation of the bog. But raising the water level is not always enough to restore the lost raised bog habitat. Thus spreading live *Sphagnum* species onto an area can stimulate the kick-start the raised bog habitat.

Figure 5.1

For peatland restoration sites which have bare soil stabilisation of the soil and re-introduction of peatland vegetation are often the initial aims for the site (alongside methods to re-wet, if needed). Brashed (finely chopped and mixed) material collected from a donor site is sometimes a viable option for achieving both prevention of further micro-erosion and to help re-introduce peatland plants.

In this particular example, a surface-milled peat extraction site (Bolton Fell Moss, Cumbria) is being revegetated using a brash mix collected from a nearby peatland. The brash contains a mix of ericaceous, graminoid and bryophyte materials which stick on to the bare peat surface and help to protect it from the wind and rain (left picture). As part of this mix, *Sphagnum* fragments (right picture) are introduced and can begin to recolonise the site.

Brash material can be spread by hand using contractors or volunteers or, for large scale bare peat sites, can be spread using a tractor fitted with low ground pressure tracks.

Photo © Emma Goodyer, Bolton Fell Moss, Cumbria, England. 2017.

Methods

Sphagnum species used for restoration can be collected in a natural peatland or can be cultivated in *Sphagnum* farms or greenhouses. In all cases, only the top 10 cm of the moss carpet should be harvested because the remaining plant material left in place will have the ability to regenerate swiftly after harvesting (usually within 3-10 years). The harvested material will contain seeds, rhizomes, spores of other peatland plants that will foster the diversity of the restored site. The area harvested should be 10-12 times smaller than the area of the restoration site – i.e. to restore 10 ha, only 1 ha of natural peatland needs to be harvested – because the fragments will be spread out in a thin layer of approximately one cm in depth. For restoration purposes, it is recommended to target *Sphagnum* species of the subgenus *Acutifolia* – i.e. the small red-brown ones – because they tend to survive and establish better in sites where water table is fluctuating and can drop to -30 cm below the ground surface. Species from the subgenus *Cuspidata* – i.e. the green *Sphagnum* growing in very wet habitat should be avoided, except for restored sites that are expected to be flooded throughout the year.

Sphagnum restoration techniques were developed by the Peatland Ecology Research Group in partnership with the Canadian Horticultural Peat industry in the 1990s. Peatland restoration projects in the case of European countries include increasingly spreading of live *Sphagnum* to kick-start growth of *Sphagnum* species. However, application of *Sphagnum* restoration techniques on large areas can be hindered by suitable donor sites to collect *Sphagnum* fragments. Depending on the area there can be a need for preparing the ground before spreading out the *Sphagnum* in order to create the proper growth conditions for the *Sphagnum* species (flat surface, residual peat pH below 5.1 and EC below 100 µS/cm).

I some cases former fertilized and calcareous top soils have to be removed prior to the spreading in others soil has been removed further down and eventually in cases to mineral soil because *Sphagnum* may be outcompeted by grasses or other nutrient-loving vegetation. Even in poorer conditions, it is recommended to remove all spontaneously grown vegetation or biological crust prior to *Sphagnum* spreading. The soon-to-be-restored surface should be rather flat or at least topography well-known and taken into account to ensure an even distribution of water after rewetting. Berms can be created to redistribute water in sloppy areas.

Right after *Sphagnum* fragments are spread, a straw mulch must be applied (3000 Kg/ha) to protect them from desiccation. A slow release fertilizer (0-13-0; at a dose of 150 Kg of phosphate rock/ha) can be applied to promote the growth of *Polytrichum strictum* - a moss species that naturally occurs with *Sphagnum* mosses and that possesses the ability to stabilize the peat substrate with its rhizoids – i.e. pseudo-roots of a moss. A fast establishment of *P. strictum* will facilitate the establishment of the *Sphagnum* mosses which will eventually outcompete *P. strictum* in the restored site.

Figure 5.2. *Polytrichum strictum* - a nurse species to *Sphagnum* that will stabilize the peat surface. The donor site should be targeted to contain some *P. strictum* within the Sphagnum carpet, but should not be dominated by this species.

Photo © PERG, Canada. 2000.

Figure 5.3. Example of species completion in a "good" and relatively open donor site dominated by *Sphagnum* of the subgenus Acutifolia, with some *P. strictum* and ericaceous shrubs.

Photo © PERG, Canada. 2000.

One of the most important factors for a success is to keep the spreading restoration area wet. S*phagnum* has its optimal growth with a water level 2 cm's below capitulum – the head of the *Sphagnum* moss. However, inundations should be avoided at all costs, especially in the first year after *Sphagnum* spreading, because it will wash out the spread fragments. Once the *Sphagnum* carpet is well established, it will be able to withstand inundation, however, water levels higher than 0,5 meter will reduce growth. Under most circumstances it can be difficult to control the water level, but it should be the aim to be maintained at all times between -2 cm and -40 cm below the surface to ensure the survival of *Sphagnum*. If water is available it is possible to establish small canals to distribute the water in the spreading restoration area.

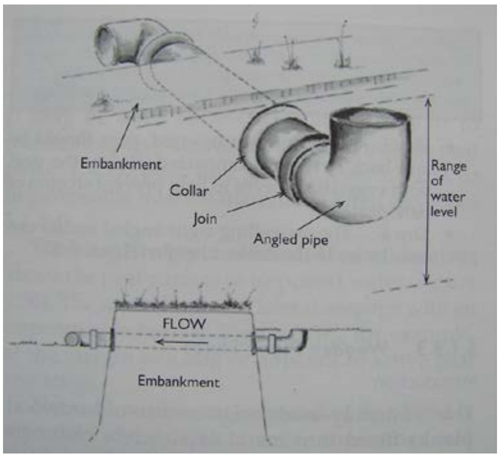

Figure 5.4. Left: A ditch canalizing the water from the inlet down along the restoration plot. Figure on the right is a sketch of how a tube can connect the restoration plot with a nearby ditch to control the inlet of water. The same arrangement can be made in the other end of the plot to control the outlet of water. Photo © Peter Hahn, Lille Vildmose. Denmark. 2013.

In Canada, large scale restoration is performed with widely-used agricultural machinery. To allow the circulation of heavy machinery and avoid creating ruts, the first steps of restoration (site preparation, plant, straw and fertilizer spreading) are performed on drained peat and rewetting is carried out right after the restoration operations are over. Restoration operations can be performed on a rewetted site when the ground is frozen. Restoration sites are prepared and levelled with a leveler or a bulldozer. Plant material can be collected with a rotovator or with a bulldozer (when moss carpet is frozen) and is then picked up and transported to the restoration area. Particular attention must be paid to reducing disturbances (like ruts) in the borrow site to ensure a quick recovery of vegetation. The plant material is usually spread with a manure spreader towed by a tractor. Straw mulch is applied with a lateral straw spreader – to avoid circulating with machinery in the freshly spread fragments – towed by a tractor, usually immediately following the tractor spreading the plant material. The straw mulch must not be chopped. The light phosphorous fertilizer is spread on top of the straw mulch with a standard conic spreader towed by a tractor[1].

[1] For more details regarding this large scale mechanized restoration technique, the Peatland restoration guide is available on the Peatland Ecology Research Group (PERG) and the Peatland restoration by Premier Tech Horticulture video is available on YouTube.

Figure 5.5. In most re-growth experiments *Sphagnum* is spread out by hand. Hereby a more evenly distribution of the *Sphagnum* is obtained.

Photo © Peatland Ecology Research Group (PERG), Canada

Figure 5.6. After the fifth growing season since restoration the total plant cover has reached up to 80 %. In time the number of species not typical for bogs is decreasing while number of species characteristic to natural bogs is increasing and species composition in restoration areas becomes comparable to that in natural bogs. For more detailed description of the scientific experimental set-up – see annex 1 for links to scientific papers.

Photo © Peatland Ecology Research Group (PERG), Canada

A mean water table depth higher than 20 cm can be recommended and the use of *S. magellanicum* fragments on wetter and *S. rubellum* fragments on drier areas. Raised water table and re-vegetation have caused remarkable changes in GHG fluxes from restored area: the emission of N2O has decreased by 1–2 orders of magnitude and the emission of carbon gases by almost half as compared to the unrestored area. Limit number of slides?

Figure 5.7. In Canada, large scale restoration is performed with widely-used agricultural machinery. To allow the circulation of heavy machinery and avoid creating ruts, the first steps of restoration (site preparation, plant, straw and fertilizer spreading) are performed on drained peat and rewetting is carried out right after the previous operations are over. Restoration operations can be performed on a rewetted site when the ground is frozen. Restoration sites are prepared and levelled with a leveler or a bulldozer. Plant material can be harvested with a rotovator or with a bulldozer (when moss carpet is frozen) and is then picked up and transported to the restoration area.

Photo © Peatland Ecology Research Group (PERG).

Here insert Figure 5.8a. The plant material is harvested in a natural peatland or a peatland that is opened for peat extraction. Only the top 10 cm of plant material should be harvested to ensure a satisfactory regeneration of the borrow site. The size of the borrow site should be ten times smaller than the surface to restore (introduction ratio of 1:10). Plant harvesting in Canada is performed with a rotovator or a bulldozer working on frozen grounds. Particular attention must be paid to reducing disturbances (like ruts) in the borrow site to ensure a quick recovery of vegetation.
Photo: PERG

Figure 5.8. The plant material is usually spread with a manure spreader towed by a tractor. This can also be performed on frozen ground. Straw mulch (3000 kg/ha) is applied with a lateral straw spreader – to avoid circulating with machinery in the freshly spread fragments – towed by a tractor, usually immediately following the tractor spreading the plant material. The straw mulch must not be chopped.

Photo © Peatland Ecology Research Group (PERG), Canada

Figure 5.9. Construction of a peat dam for rewetting with an excavator. After construction of the peat dam and spreading of *Sphagnum* and straw, the area is rewetted with an excavator. In very wet conditions it can be impossible to drive on the prepared area. In such situations it might be necessary to find a solution where the *Sphagnum* and other growing material like straw or heather can be spread from the edge of the spreading plot. Using a straw chopper mounted on a tractor it is possible to spread *Sphagnum* and straw out on larger plots. However, the experience is that the maximum size of the plots is 0.2 ha if the material should be evenly distributed in the plot.

Photo © Peter Hahn, Lille Vildmose 2013

If restoration steps are preformed accordingly to what is described previously and if the restored site is rewetted efficiently, a fast *Sphagnum* establishment is expected (within 5-10 years). Other peatland plants – ericaceous shrubs, sundews, cotton - grass, and pitcher plants – are also expected to become abundant in the restored sites, especially if the material was harvested from a donor site containing a diversity of peatland plants. In a "dry restoration" approach – site efficiently rewetted, but not inundated – the restored ecosystem is expected to eventually become a carbon sink – annually accumulates more carbon in its living plant tissues than the quantity of carbon loss through decomposition of organic matter.

Figure 5.10

Where local material is not available to support the re-introduction of peatland vegetation to a restoration site, it can be grown off-site and brought in. In the UK, Micropropogation Ltd use micropropogation to produce large numbers of individual Sphagnum plants or propagules that can be applied to a restoration site in a number of ways:

Top photo: A product called 'Beadamoss'. Gel beads contain tiny fragments of Sphagnum moss. These can be spread onto a site by hand or onto large sites by helicopter. The gel protects the propagules from drying out whilst they get established and begin to grow into whole plants.

Middle photo: A product called 'Beadagel'. A gel slime contains tiny fragments of Sphagnum moss. As the slime dries out it sticks the Sphagnum fragments onto the peat surface which helps them to establish. This product is more suited for targeted application to bare peat areas and quickly establishes a good coverage of Sphagnum moss.

Bottom photo: Sphagnum moss can also be grown on to a more mature stage off site and introduced to the restoration project as plug plants. This method has a good success rate and can deliver good coverage of Sphagnum moss within a short time frame.

Photos © Emma Goodyer 2016

6. Rewetting by Paludiculture

Contributors: Tobias Dahms (DE)

Introduction

In many parts of the world, an increasing demand for productive land constitutes an obstacle for peatland rewetting and threatens pristine peatlands. Continued drainage and cultivation of the peat soils can lead to a complete loss of the soil resource and the carbon it contains. Heavily drained and cultivated peat soils can become 'wasted' and unsuitable for continued, profitable agricultural use.

Land use with plants and machinery adapted to wet site conditions can offer a solution for the trade-off between agricultural production and peat soil protection.

Some paludiculture systems offer minor improvements from the most severe degradation on agricultural peat soils and might help to stem carbon and soil loss. Other paludiculture systems might offer a wider range of -multiple benefits including supporting wetland species/semi-natural vegetation, flood and water quality benefits etc.

Paludiculture (Latin 'palus' = swamp), is the agricultural or silvicultural use of wet and rewetted peatlands. It is a paradigm shift adapting site conditions to requirements of conventional agriculture to adapting cultivation to permanent or seasonal wet conditions resulting in significantly lower environmental impacts. Adapted cultivation includes using spontaneously grown or cultivated biomass, adapted machinery and adapted harvesting processes. . It is not restricted to the production of plant based products and can also encompass wetland grazing and livestock rearing systems such as the farming of water buffalo for dairy and meat.

Beside traditional examples of wet peatland use such as reed cutting for thatching, large-scale implementation of paludiculture long term experience is still rare. Paludiculture aims at rewetting formerly drained peatlands. From a biodiversity point of view certainly pristine peatlands should be conserved and restoration of peatland habitat as the second option in order to attempt to recover the broad range of ecosystem services that have been lost, including biodiversity and nature conservation benefits.

Where local economies and land use pressures dictate that maintenance of a natural peatland habitat or the restoration to a semi-natural peatland habitat is not possible, paludiculture offers a solution to enable an economic use of the peatland without completely compromising the soil resource and resulting in large GHG emissions. But even though pristine peatlands provide ecosystem services and conserve threatened flora and fauna and should be protected entirely, it might be a second best solution for sites where the increasing demand for productive land drives peatland drainage.

Biomass from different species can be used as food, feed, fiber and fuel but also as raw material for industrial biochemistry or construction.

Benefits for nature conservation

Paludiculture is not focused on nature conservation but on the productive use of wet peatlands. Its practices may contribute to nature conservation objectives but might also in some cases contradict these. Possible synergies might be:

- Paludiculture can be intermediate stage between drained use and nature conservation. It might contribute through nutrient removal and vegetation management including opportunities for re-establish natural hydrology to establish site conditions necessary to both conservation and climate mitigation objectives.

- It may reduce the costs of conservation mowing by providing additional income and reducing biomass disposal costs on sites where regular mowing is necessary to sustain the conservation value.

- As a buffer surrounding rewetted conservation areas it can reduce the impacts and conflicts from the surrounding areas and reduce nutrient loads of the incoming water. Such a buffer area can also contribute to the water regulation in the conservation area and climate change adaption.

- Areas used for paludiculture can form a corridor between two conservation areas, facilitating migration of species.

- Wet agriculture can help to increase the acceptance of parties affected by the rewetting. It might help stakeholders who depend on the use of peatland resources to adapt their practices of peatland use. Supporting local communities to adopt alternative production practices and ensure that they profit from the rewetting is crucial for many projects.

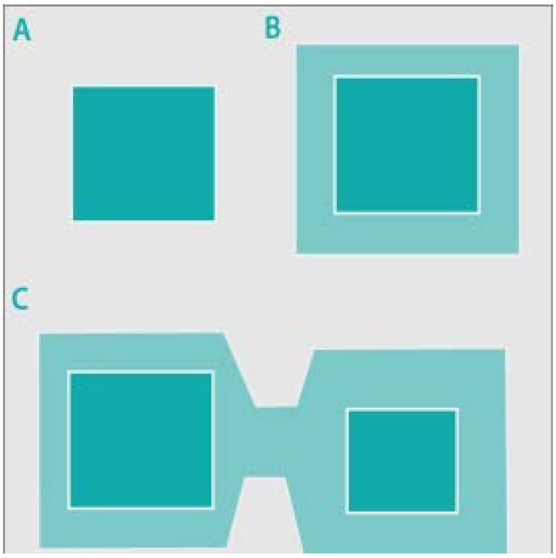

Fig. 6.1.

Areas used for paludiculture can constitute a buffer zone between areas rewetted for nature conservation and the surrounding agricultural area (B) and thereby reduce conflicts which may occur if there is no buffer area (A). Such buffers may also form a corridor between two conservation areas facilitating species migration (C). Grey: surrounding agricultural area, light cyan: area used for paludiculture, cyan: nature conservation area (adapted from van de Riet et al. 2014)

Plants

The Database of Potential Paludiculture plants (DPPP) [link] lists more than 1,000 wetland plants. But only a fraction of those plants combine the preservation of the peat carbon stock (perennials of which the aboveground biomass is used) with an existing or highly probable market demand. Nutrient and water availability as well as water quality are further factors which restrict the cultivation of paludiculture plants on respective sites. Examples for potential, traditional and tested paludicultures are given in the table below.

Table 6.1. Examples for potential and tested paludicultures (modified after Abel et al. 2013, Joosten et al. 2012).

Species	Region & sites	Utilization
Alder (*Alnus glutinosa*)	Central Europe fen, oligo-eutrotrophic	Timber, fuel
Cattails (*Typha* sp.)	Central Europe, North America, West Africa fen, polytrophic	Construction material (e.g. insulation), solid fuel, fermentation, fibers
Common reed (*Phragmites australis*)	Europe, China fen, polytrophic	Construction material (e.g. thatching), paper, solid fuel, fermentation
Illipe Nut (*Shorea stenoptera*)	Tropics	Cocoa butter substitute
Jelutung (*Dyera sp.*)	Tropics	Latex
Sago (*Metroxylon sagu*)	Tropics	Starch
Sphagnum sp.	Worldwide bog, oligotrophic	Growing media, revitalization
Water buffaloes	Europe, Asia	Cheese (mozarella), meat, conservation grazing

7. Removal of nutrients – airborne and waterborne eutrophication

Natural bogs are oligotrophic or mesotrophic. Most agricultural techniques in or around bogs aim at amending them with nutrients, therefore destroying the trophic conditions for maintaining or restoring their nutrient-poor status. This may also occur accidentally by drainage ditches which provide access of nutrient rich water into the bog. On a larger scale, any bog located close to or downwind of regions with intensive agriculture, heavy traffic or industry is exposed to elevated nitrogen deposition.

Under such conditions, vegetation in bogs is subject to pronounced changes as bog peat forming species are no longer competitive. The following measures may help in alleviating exposure to excess nutrients in bogs:

Vegetation and topsoil management- biomass removal

Vegetation adapted to eutrophic conditions may be detrimental for the establishment of bog typical vegetation and superficial peat may be nutrient loaded or hosting diaspores or roots of undesired vegetation. In addition, this peat may be severely decomposed; having lost the physical conditions for the successful establishment of bog forming plants. Under these conditions, it may necessary to remove this vegetation and the affected superficial peat. This needs to be done only after consulting experts and with care to avoid the removal of too much valuable peat the restoration measure intends to protect.

Control of hydrological inputs

When restoring a bog, blocking of ditches should not only stop the drainage of bog water to the surrounding areas, but also the inflow of nutrient loaded water into the bog. In case the climatic conditions for bog formation are still given, the water in the bog should become oligotrophic again. Monitoring of the water table as well as nutrient concentration in the restoring bog is advisable.

Control of grazing levels

Grazing may provide an efficient means of controlling vegetation in bogs. This benefit must be weighed against the potential nutrient input by animal feces and damage by trampling.

8. Conclusion

Restoration of bogs has proven successful initiation of a restoration process of biodiversity of natural or near-natural hydrology in degraded bogs. By relative simple methods it is possible to restore hydrology and initiate a development towards natural bog vegetation and conditions to the benefit of biodiversity and climate change.

This report brings no conclusions but shares experiences on ways and means to restore degraded peatland areas.

It is recommended to consider collecting similar experiences on the restoration from geographically different parts of the world including the tropics where there are a number of experiences. Moreover focus could be broadened up and another compilation of experiences could have focus on the restoration of other peatland types.

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Annex 1 Link list to information on peatland restoration and case studies

This list links to websites, publications and projects dealing with restoration of bogs and peatlands. The list is not covering all available information and literature on the subject but can serve as inspiration.

IUCN Peatland programme

IUCN UK Peatland Programme Demonstrating Success Booklet series showcase successful peatland restoration projects from across the UK and Internationally.

Global Peatland Restoration demonstrating Succes. IUCN 2014 http://www.iucn-uk-peatlandprogramme.org/sites/www.iucn-uk-peatlandprogramme.org/files/IUCNGlobalSuccessApril2014.pdf

UK Peatland Restoration Demonstration Success. IUCN 2012: http://www.iucn-uk-peatlandprogramme.org/sites/www.iucn-uk-peatlandprogramme.org/files/IUCN%20Demonstrating%20Success%20Booklet_0.pdf

Greifswald Mire Center

www.paludiculture.com

www.greifswaldmoor.de

Projects under the EU LIFE programme

Raised Bogs, Latvia; Website: http://www.purvi.lv/en/actions/d4

Publication,

LIFE Lille Vildmose; website: www.lifelillevildmose.dk

LIFE Aukstumala, Lithuania; website: http://lifeprojektai.lt/en/life-projects/lithuanian-life-projects/LIFE12-NAT-LT-000965/

LIFE Raised Bogs in Denmark; website: https://www.raisedbogsindenmark.dk/

LIFE East, Denmark; website: http://lifeeast.dk/

Large scale mechanized restoration technique:

Canada: http://www.gret-perg.ulaval.ca/no_cache/en/pergs-publications/technical-guides/restoration/?tx_centrerecherche_pi1[showUid]=6192

Handbooks

Fen management handbook:
http://ec.europa.eu/environment/life/project/Projects/index.cfm?fuseaction=home.showFile&rep=file&fil=FENS_management_handbook.pdf

Grazing guidance: https://www.snh.scot/sites/default/files/2017-11/Guidance-Peatland-Action-guidance-on-peatland-grazing-A1268255.pdf

Peatland Action Restoration Guidance videos:
https://www.youtube.com/playlist?list=PLSTn6yg6zH__XM-Mw7fKNoGsVYo31B5VH

RSPB Water level management structures for conservation:
http://ww2.rspb.org.uk/Images/Water_management_structures_tcm9-214636.pdf

Conserving Bogs. The management Handbook. Stuart Brooks, Rob Stoneman, Astrid Hanlon & Tim Thom. 2nd edition 2014: https://issuu.com/peat123/docs/conserving_bogs

Raised Bog management. For Biological Diversity Conservation in Latvia:

http://www.purvi.lv/files/2014/7/1/purvi_web.pdf

Videos

Peatland restoration
https://www.youtube.com/watch?v=Vyhfz39d4uw

Scrub clearance
https://www.youtube.com/watch?v=uR0wpy7e4ok&index=3&list=PLSTn6yg6zH__XM-Mw7fKNoGsVYo31B5VH

Surface Smooting
https://www.youtube.com/watch?v=h-nPehdDQsk&index=5&list=PLSTn6yg6zH__XM-Mw7fKNoGsVYo31B5VH

Bunding
https://www.youtube.com/watch?v=Yw8Y039oX-U&index=6&list=PLSTn6yg6zH__XM-Mw7fKNoGsVYo31B5VH

https://www.youtube.com/watch?v=0wXbhcl-Mi8&index=8&list=PLSTn6yg6zH__XM-Mw7fKNoGsVYo31B5VH

Ditch blocking
https://www.youtube.com/watch?v=Gmoji9SYheE&index=9&list=PLSTn6yg6zH__XM-Mw7fKNoGsVYo31B5VH

https://www.youtube.com/watch?v=v2JA79U7Cik

Grip-blocking (blocking drains)
https://www.youtube.com/watch?v=d9jCiPW3ZSU

Annex 2 Terminology

The list is based upon definitions in Mires and peatlands in Europe (Joosten *et al*. 2017).

Bog Mire only fed by precipitation

Ombrotropic Only supplied with nutrients by the atmosphere

Paludification The formation of waterlogged conditions

Peatland An area with or without vegetation with a naturally accumulated peatland layer at the surface

Restoration Management to assist the recovery of a degraded peatland ecosystem