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Draft Briefing Note on practical peatland restoration

Ramsar Briefing Note on practical peatland restoration

Purpose

This Briefing Note aims to provide peatland managers with practical field guidance to peatland restoration.

Background

Resolution XIII.13 'Restoration of degraded peatlands to mitigate and adapt to climate change and enhance biodiversity and disaster risk reduction' requested the Scientific and Technical Review Panel (STRP) to consider, related to the fourth Strategic Plan 2016-2024, the further elaboration of practical experiences of restoration methods

- for peatland types not yet covered by Ramsar Convention guidance,
- based on the integrated approach to ecosystem restoration.

In its 2019 Meeting the STRP decided to produce a Briefing Note on practical peatland restoration, building on Ramsar Briefing Note No.4 'The benefits of wetland restoration' and Briefing Note No. 10 'Wetland Restoration for Climate Change Resilience', and an associated Technical Report no xx 'Ramsar Global Guidelines for Peatland Rewetting and Restoration' (2021).

Relevant Ramsar documents

Summary

Compliance with the Sustainable Development Goals and the Paris Agreement will require peatland rewetting and restoration on a hitherto unprecedented scale. In association with Ramsar Technical Report no xx 'Ramsar Global Guidelines for Peatland Rewetting and Restoration', this Briefing Note presents key information on practical peatland rewetting and restoration on site. It formulates general principles applicable to all peatland restoration practices, and provides detailed information on a wide range of restoration techniques, including peatland rewetting by building blocks, bunds and screens and by reducing leakage.

It addresses relevant revegetation and vegetation management options, including peat swamp reforestation in the tropics and tree and shrub removal, revegetation and the re-instalment of traditional management to restore open mire vegetation in the temperate and boreal zones.

Key messages

- The rewetting and restoration of degraded peatlands on a hitherto unprecedented scale is essential to comply with the UN Sustainable Development Goals and the Paris Agreement.
- This Briefing Note provides information on the most important rewetting and restoration techniques, complementary to the Ramsar Technical Report, which explains backgrounds, goals and implications.

- The information in this Note and the referred literature provides guidance to inspire taylor-made, practical solutions for local problems.
- The most important restoration technique is rewetting, i.e. raising the annual average water table to around the peat surface. This must be done by blocking drainage structures (ditches, canals, gullies) and – if this is insufficient to re-establish high and stable water levels – by building/facilitating surface structures (bunds, hummocks, buttressed and stiltrooted trees) to slow down surficial water outflow to create a water buffer for dry seasons above the peat surface.
- Re-establishing a suitable vegetation is vital for protecting the peat body, re-installing peat formation, supporting biodiversity and often also for restoring adequate hydrological conditions.
- Revegetation may rely on spontaneous regeneration but may in many cases require re-introduction of plants, e.g. by hay, sod or moss transfer, seeding or planting.

The issue

The rewetting and restoration of degraded peatlands on a hitherto unprecedented scale is essential to comply with the UN Sustainable Development Goals and the Paris Agreement. This will require clear and comprehensive technical guidance, which this Briefing Note aims to provide, additional to the more conceptual guidance in the Ramsar Technical Report. Central in peatland restoration is rewetting, i.e. bringing the water table back to at or over the peat surface. Additionally the re-establishment of peat-forming c.q. peat-protecting vegetation is required to prevent further deterioration.

This Briefing Note summarizes the main principles and techniques of peatland rewetting and restoration on site. Together with the provided references and the associated Technical Report it may provide sufficient inspirational guidance to peatland managers and practical decision makers to derive taylor-made solutions for local restoration problems and conditions.

1. Introduction

A significant part of the world's peatlands has been transformed and drained causing large environmental problems. This brought peatland restoration on the agenda of the Ramsar Convention and many other national and international policy frameworks.

This Briefing Note gives information on practical implementation aspects of peatland rewetting and restoration. Degradation caused by activities and developments outside the peatland is not addressed. The necessary measures depend on the peatland type, on how strongly the peatland is degraded and on what the final restoration aims are. Further background considerations can be found in the Ramsar Technical Report No.xxx 'Ramsar Global Guidelines for Peatland Rewetting and Restoration'.

Existing guidance

To find practical solutions for local problems, it is good to orientate on existing information. Useful peatland restoration manuals are Kozulin et al. 2010 (Belarus), Stańko et al. 2018 (Poland, alkaline fens), Dinesen & Hahn 2020 (Northern bogs), Similä et al. 2014 (Finland), Van Duinen et al. 2017 (Netherlands, bogs), Grosvernier & Staubli 2009 (Switzerland), Mackin et al. 2017 (Ireland), Wheeler & Shaw 1995, Thom et al. 2019, Ferré & Martin-Ortega 2019 (United Kingdom), Giesen & Nirmala Sari 2018, the Indonesian Peatland Restoration Agency (http://brg.go.id/panduan/), Parish et al. (2019) (Tropics with focus on SE Asia), Landry & Rochefort (2012) and Quinty & Rochefort 2003 (Canada). This Briefing Note summarizes the major insights from this and other guidance.

General principles

Some principles apply to all practical peatland restoration:

- Peat formation requires a rather narrow range of (high) water levels. Peat formation is hampered both by too low (boosting peat oxidation) and too high water levels (reducing plant production, increasing water erosion).
- Peat soil wetness has to be almost permanent, because peat decomposes 10 times faster when drained than that it builds up when sufficiently wet.
- Peat is almost as light as water and therefore easily erodes if not protected. Restoration must therefore disperse water flow (not concentrate it!) and re-establish vegetation on bare peat surfaces. Furthermore peat should be kept wet to prevent oxidition.
- Peat is soft and heavy machinery may easily sink away, necessitating adapted action and the employment of experienced workers.
- Water flows from high to low. In order to keep access, rewetting activities must start from the highest point and work successively downwards.
- To save costs, local materials (peat, wood, sods, sand) are prefered for making blocks and bunds. The use of foreign materials (hardwood, plastics, metal, geotextiles) may, however, be necessary to construct durable and optimally performing devices.
- Any construction will over time deteriorate, be destroyed (e.g. when blocks frustrate local access) or its 'valuable' materials may be stolen. Blocking systems should therefore be constructed inherently robust by:
    - Reducing pressure and erosion risk for each block by building a cascade of blocks with limited water level differences (0.10 - 0.25 m).
    - Not allowing water to run over a block.
    - Infilling of ditches and canals (also partial) to allow them to be overgrow and filled in by vegetation, which reduces water steps over and pressure on the blocks.
- Let nature do the work: In the end, nature must restore itself – people can only help but not fully control.

Building blocks and bunds

High and stable water levels are crucial for peatlands. Therefore the construction of blocks (to dam ditches and canals) and bunds (to slow down water discharge over the surface) is central in peatland rewetting and restoration. General recommendations with respect to building blocks (dams) and bunds (dikes, embankments) include:

- Work if possibly under dry conditons, i.e. in the driest period of the year, or create locally drier conditions by constructing temporary dams up- and downstream and by pumping.
- Avoid working during frost when peat and clay are difficult to handle and have an unstable structure.

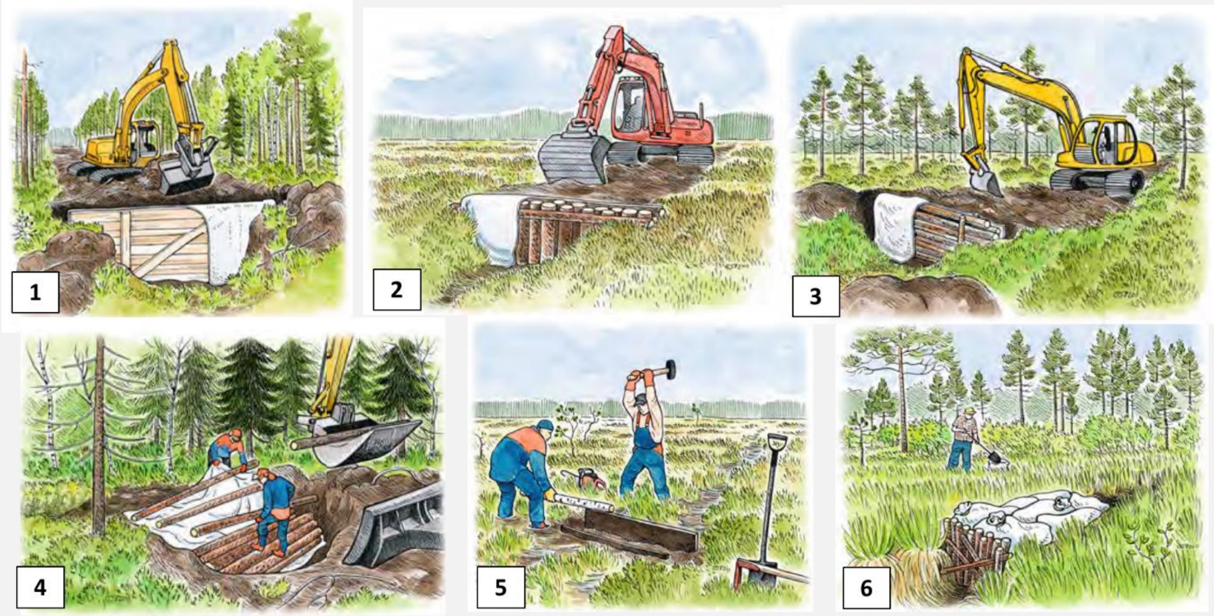
- Start damming at the most upstream part of the drainage system to reduce water pressure downstream (reducing risk of block failure) and to keep the area as long as possible accessible.
- The distance between dams should reflect the surface slope: larger spacing on gentle slopes and closer spacing on steeper slopes.
- Places less suitable for block locations include sites with large plant tussocks and trees (whose roots are difficult to cut through and may provide a conduit for water seepage), small depressions along the drain profile, and cracked, oxidised and eroded peat banks (where water may seep through).
- To aid future monitoring, record the location of all blocks using sub-metre accuracy GPS.

Materials

- Blocks do not have to be completely impermeable, but rather have a permeability comparable to that of the surrounding peat.
- Low humified peat (Von Post H3 and below) has a rather high hydraulic conductivity. Preferably use wet, more decomposed peat (Von Post H6 – H8) to build leak-proof blocks. Highly oxidised peat, e.g. scraped off peat or material excavated when the ditches were dug, may have lost its water retentive properties and should be avoided for block building. This material can be used to fill the ditches.
- Wet peat is heavy and is best taken from the immediate vicinity upstream of the block. If peat is removed from downstream of the block, scars remain more noticeable. Care should be taken that a string of excavation hollows will not act as a parallel drain.
- When constructing large dams of wood with peat, it may be necessary to add stones or cement to solidify the structure and counteract floatability.
- Use wood that does not easily rot. Minimize the risk of rotting by keeping the constructions submerged in water or covered by well-compacted peat.

Block construction

- Vegetation should be cleared out where blocks are to be built, to ensure a good seal.
- To prevent erosion, the width of the block must exceed that of the drain/canal on both sides to make sure that the water doesn't flow around the block and returns to the drain. Installing the block at an angle (i.e. not perpendicular) to the drain may discourage water from flowing round the block.
- Blocks must be big enough and compressed carefully to ensure they can withstand water pressure even during flood seasons. Blocks should be at least two metres long in the direction of the ditch.
- The top of the blocks should be higher than the surrounding ground level to compensate for shrinkage and to allow the impounded water to flow laterally away over the peatland surface.
- Blocks and bunds should finally be covered with vegetation, to keep them in place and to reduce the risk that they will be washed away by floods. Plastic plates must be covered to prevent degradation by UV light.



Various blocks in restoration projects in Finland. 1. Block from tongue-and-groove boards in large or badly eroded ditches. 2-4 Log blocks constructed where suitable logs are easily available (e.g. from trees felled on the site). If the peat is deep, the logs can be sunk vertically into the peat, where peat deposits are only shallow the logs can be put in place horizontally. The block should then be covered with geotextile and peat. Log blocks can be stabilised with the help of supporting logs aligned at right angles to the other logs. 5. Blocks of plywood to block shallower ditches. Board should be sawn to sizes with greater length and depth than the ditch. To put them in place grooves can be cut in the peat using a long-reach chainsaw. The boards can then be hammered into place e.g. with a sledgehammer. Peat should then be shovelled in between the boards and packed tightly. 6. Jute sacks filled with compressed peat for repairing blocks in restored sites where excavators can no longer work. Sacks can be fixed in place using wooden stakes hammered into the peat. The geotextile used to cover the boards is only partly shown to enable the underlying structures to be seen. (Similä et al. 2014, Illustrations: Tupu Vuorinen).

Dam design

The following block types are fit for small ditches:

- Peat blocks of well compacted peat to be used where the slope and water pressure are low. The wider the block (in the direction of the ditch), the more stable it is. In order to assure compaction, an excavator should press each layer of peat added.
- Blocks of wooden planks (fig. 1a) are affordable and efficient. The planks should be sunk at least 60 cm into the peat (and if possible into the mineral soil) and should surpass at least 60 cm on each side of the ditch to avoid water leaking through the block. Well-compacted peat placed upstream and downstream from the plank should stabilize and cover the installation. Similar blocks can be made from metal panels, plexiglas or corrugated plastic.
- Blocks with double panels (fig. 1b) are appropriate when the water level difference accross the block is more than 50 cm. They are constructed by installing two perpendicular panels in the ditch 3 - 4 m from one another and filling the space between the panels with peat or sawdust.

- Blocks from bales of straw and heather brass can be used in small ditches. The bales are compacted and solidified with logs or other types of stakes inserted deeply into the bottom of the ditch.
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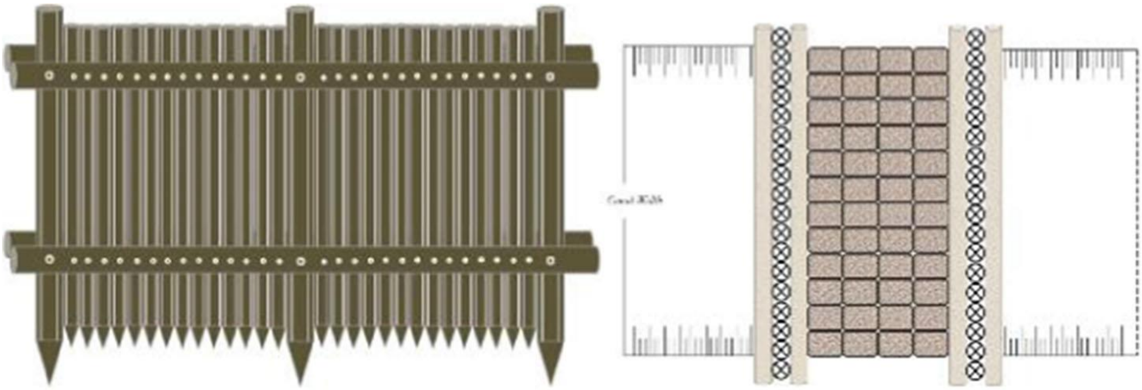
In order to improve the seal of the block, a geotextile can be added.



(a) (b)

Fig. 1: Block designs of single plank dam (a) and composite plank dam (b) (Dohong et al. 2018).

The following block types are fit for mid- and large-sized drains, ditches and canals:

- Compacted peat blocks are cheap, rapidly constructed and, when well-compressed, last 10 years or (much) longer. However, they are easily damaged by persons wanting to re-open waterways.

- Solid flow-around blocks stop the draining effect of channels completely. The water in the channel rises to the level of the ambient surface and then bypasses the block in a broad front. Solid blocks are made from peat or other local soil material, possibly combined with wood. The width of the block on the top should be not less than 3 m for channels <4 m wide and 5-10 m for wider channels. For the side slopes a 30° angle to the bottom of the channel is recommended. The upper level of the dam after compacting should rise 0.7-1 m above the surrounding surface (at a distance of 10-20 m from the dam) of the peatland. The dams should extend to at least 3 m beyond the edge of channels, but in case of older, more subsided channels, all the way to the prevailing surface of the peatland. Places where water can only flow out in a narrow front should be reinforced to prevent erosion.

- Blocks of wooden planks consist of wooden tongue and groove planks piled horizontally or vertically and nailed together (fig. 2 left). The planks have to be inserted into the peat at the bottom of the ditch as deeply as possible and into the walls of the ditch (at least 60 cm) to assure solidity and avoid erosion. To assure impermeability, a geotextile or a polyethylene sheet can be installed at the upstream face of the planks. Well compacted peat up- and downstream of the dam will cover and solidify the construction.

- Double wooden blocks with backfilling are used where water pressure is larger. These blocks consist of planks nailed and attached to U form structures for more stability.

- Plastic piling blocks are recommended for ditches that store much water, like in sloped peatlands or principal ditches into which secondary ditches flow. This type of block should be inserted as deeply as possible into the mineral soil in order to avoid leakage. The block can be doubled for more solidity.

- Box or coffer blocks consist of box-like structures usually made of wood and infilled with bags filled with sand or manually compacted peat. Box blocks are rather expensive, require lots of material that has too be brought in (timber, sand bags), take long to construct, last without maintenance only short time, and are easily damaged.

- Rock-filled blocks with piling wall (fig. 2 right) are used to regulate runoff by overflow in case of a high water flow rate (more than 2 m^3/s). In this block, a wooden wall is placed perpendicularly to the ditch and inserted very deeply. At each side of the block, a pile of peat is placed sloping away from the installation over a distance of 5 to 20 m and a layer of stones at least 20 cm thick added on top to prevent erosion. The dams should be constructed with no water in the watercourse, using temporary dams and water pumped out or a temporary bypass channel.

- Water-discharge structures with concrete flumes inserted in an earth block, which allow regulating water runoff in channels with high water flow rates (3-8 m^3/s).

- Stone gabions are metal cages welded together, filled with stones and constructed in a ditch that reaches the mineral soil. Not the stones block the water flow, but more the peat that settles and clogs the spaces between the stones. Gabions can be expensive if the material must be transported onto the site.

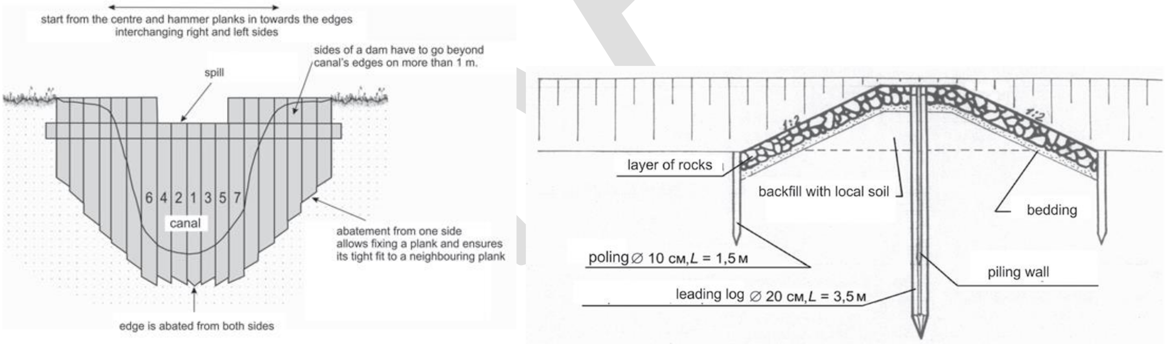


Figure 2: Overflow piling block made of planks (left) and rock-filled block with piling wall (right). After Kozulin et al. (2010).

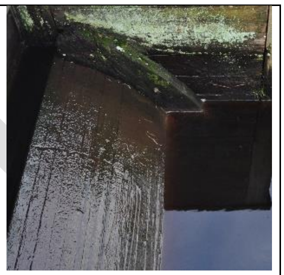
Spillways and bypasses

- If a spill-over construction has to be installed in a block, take care that the water backed up behind a block reaches the next upstream block well above its base to prevent falling water causing scouring of the drain base in front of the block. The difference in water levels upstream and downstream of the block should generally be limited to 20-30 cm to rewet the major part of the peatland.

- V-shaped notches allow increasingly more water to leave the area diffusely when water levels rise. Many small notches are in this respect more effective than a single large notch (fig. 3)

Fig. 3: In order to disperse water flow, several notches in a spillway are better than one single notch (modified after Landry & Rochefort 2012).

Whereas fixed bypasses (fig. 4a) always lead to a suboptimal peatland water level, flexible flap weirs (fig. 4b) enable to reconcile the opposing interests between highest possible water levels and continued accessibility in a simple way.

		
Fig. 4a: Box block with large spillway, Sebangau NP, Central Kalimantan. Photo: Wim Giesen.	*Fig. 4b: Flap weir (Klappstau) in NW Germany with a fully passable, flexible weir.*	*Fig. 4c: Detail of flap weir. Photo: Hans Joosten*

Backfilling

Backfilling is the most effective method to restore the water level of peatlands, but requires much peat or other material. For backfilling (infilling) the following considerations apply:

- Material used should be nutrient poor and rather impermeable. Dried, oxidised and mineralised peat is less suitable.

- As the peat is packed into the ditch it should be compacted to decrease permeability. The volume needs to be greater than the volume of the ditch because of compression and loss of structure.

- Sawdust only needs to come to the level of the peatland as wet sawdust does not settle and does not need to be compacted. Sawdust mixed with wood chips can be interesting for eliminating logs of trees cutted down during site preparation.

- At sufficiently short intervals dams should be formed to ensure that water rises to the desired level.

- To prevent erosion, the surface should be dressed with vegetation.

Gullies

- It is essential to stabilize the gully head to prevent head-cutting and upward expansion.
- Like ditches, gullies can be blocked or filled. Revegetation will aid peat stabilisation.
- The height of gully blocks may remain lower than the surface of the adjacent peatland. This also means that the water table will not rise to the surrounding peat surface.
- Block spacing should be a function of gully slope and depth.
- For peat gullies block widths should not exceed 4 m. For wider gullies wooden fencing, plastic piling and gabions are more effective.

Bunds (berms), dikes and screens

A bund is an elongated impermeable embankment or barrier. It may be used to restrict water loss or to impound open water. Types of bunds are (fig. 5):

- Surface (or internal) bunds, which increase water levels on oversteepened slopes. A bund may require the insertion of a plastic membrane to decrease its permeability if only slightly humified peat is available.

- Wall (or peripheral) bunds, which minimise lateral water loss at the edge of an isolated peatland remnant. Wall bunds have to be strong enough to resist large water pressure. Wide bunds work better and should be reinforced or be wider at places where pressure is likely to be greater. Wall bunds may include a low permeability core/liner to limit water flowing through and underneath the bund. In steeply convex, or irregular, massifs it may be necessary to have two or more concentric bunds if wet conditions are to be maintained at the summit.

- Parapet bunds are used to raise the water level over the surface as a storage to limit annual water level fluctuations. Parapet bunds are most suited where the surface is flat and peat prevents vertical water losses.

- Bale bunds of heather or straw bales or coir logs are applied to reduce erosion and waterflows across bare peat areas.

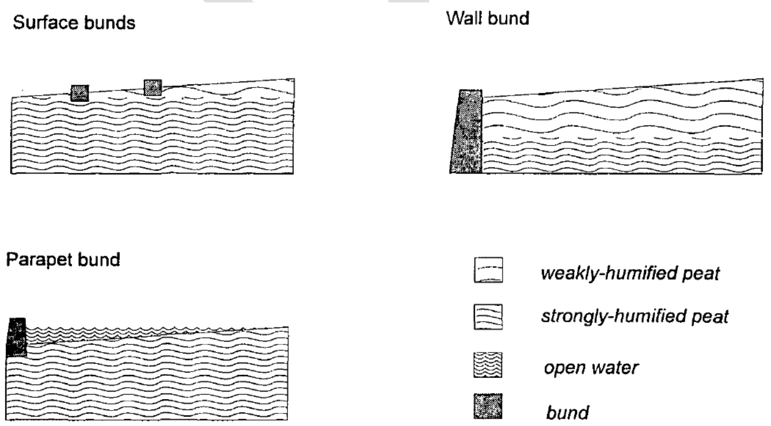


Figure 5: The main types of bund (Wheeler & Shaw 1995).

For building surface and parapet bunds the following considerations apply:

- Surface peat and vegetation at the location of a bund have to be removed prior to building to provide better contact between bund and peat surface and limit the risk of leaking.
- Building bunds on slightly humified peat is less effective than on strongly humified peat, because the former may cause leakage underneath the bund.
- Bunds can be made from humified (black) peat, whether or not in combination with a foil screen, a wooden sheet or impermeable mineral materials – often clay. The presence of wood, branches or other debris in the peat can weaken the bund and lead to leaking.
- The peat has to be compacted thoroughly to ensure imperviousness and make it more resistant to water and wind erosion. The use of heavy machinery is recommended.
- The size and height of a bund depend on its purpose. A height of 40 to 50 cm after compaction usually provide sufficient surface water storage. Surface and parapet bunds must initially be built too high to allow for settlement (typically 20-25cm).
- Bunds should be topped with turves to prevent desiccation and erosion.
- Wide bunds are more resistant to water pressure. Higher bunds freeze deeper than the surrounding area making them more resistant to water erosion in spring.
- To regulate water levels to prevent overflow erosion, devices must be installed that allow discharge of surplus water. The simplest and cheapest solution consists of a drainage pipe with a pivoting knee. A qualitatively better solution is an adjustable weir, which allows to keep the level low in the early years and to slowly raise it as required.
- It is important to determine the correct height of the overflow. Large bodies of deep open water hamper vegetation re-colonisation and attract wild fowl and gulls, which cause nutrient-enrichment.
- The compartments must have a largely horizontal surface. The distance between the bunds must be such that the highest part of a compartment does not remain too dry, while the lowest part does not get too deep water.
- Smaller compartments require a greater length of bunds but break up the area of standing water and prevent wave erosion from damaging the bunds.
- The re-wetting of the peat inside the bund will cause the peatland to rise, potentially altering gradients and water flow characteristics.
- Compartmentalisation must consider future developments. If the compartments should one day become a contiguous peatland, the compartments must be able to grow seamlessly together in terms of their mutual height differences.

Screens

A foil screen can be used to prevent belowground water flowing out of a reserve (or from nutrient rich water from surrounding land flowing in) or to prevent groundwater flow between adjacent compartments with different levels.

- Polymer foil is delivered in long rolls. The foil should be installed in a continuous length to avoid the risk of leaks. The foil is typically run along the wall of a dug trench and backfilled with excavated soil. The foil may extend slightly above the soil surface within a soil bund.

- Screens may also be made of two layers of geotextile polypropylene fabric with bentonite granules inbetween. Bentonite is a type of clay that sticks, binds, seals and thickens when it gets in touch with water. A bentonite screen may be used to make dikes waterproof.

Reducing leakage

Sites where downward seepage is concentrated (e.g. ditches dug into the mineral subsoil) can be clogged by bringing in peat or other impermeable material (clay, bentonite).

Revegetation and vegetation management

The approach to revegetate bare areas depends on the type of peatland, the state of degradation, and the plans for the area. If remnants of original vegetation remain, rewetting may be sufficient for the vegetation to regenerate. Revegetation of sloping bare peat may require the application of lime, fertilizer and a nurse crop (e.g. composed of amenity grasses) to provide initial ground cover.

Reforestation of tropical peat swamp forests

The reforestation of tropical peat swamp forest is necessary to restore peatland hydrology (see Ramsar Technical Report).

- Unassisted forest regeneration depends on the availability of seed dispersal agents (wind and small- to medium-sized birds) and on sprouting from vegetative remnants. Natural regeneration is in the absence of fire probably achievable, but will be slow with initially low species diversity (Blackham et al. 2014).

- If natural regeneration is insufficient, enrichment planting can assist recovery. Species used should have a broad ecological tolerance (pioneer species) and able to cope with exposure to direct sunlight, desiccation in dry months, and some degree of flooding in the wet season (Parish et al. 2019).

- Seedlings must be collected from the wild or from tree nurseries. Local seed provenance should be prioritized. Planting density could vary from 400 - 2,500 seedlings per ha (5 × 5m or 2 × 2 m, respectively).

- One month after planting, seedlings should be checked and any that have died be replaced. Weeding should continue until seedlings (also in case of natural regeneration) rise above the height of ferns and sedges (about 1.5–2 m).

- If pioneer species are well established, shade tolerant or requiring species can be planted to speed up succession towards a mature mixed peat swamp. Beneficial (timber and non-timber forest products) species should be utilised near villages or when restoration areas belong to a particular community (Graham et al. 2017, Parish et al. 2019).

- Detailed guidance on replanting is given in Nuyim (2005), Giesen & van der Meer (2009), Mahyudi et al. (2014), Wibisono & Dohong (2017) and Parish et al. (2019).

Forest, trees and shrub removal

Some peatlands naturally support tree-cover. However, in many cases the presence of trees is due to planting, invasion or expansion of trees following drainage of originally treeless or sparsely-wooded peatlands. Peatland restoration may then involve the removal of trees.

- Rewetting is the most efficient way to remove or suppress tree and shrub growth in originally open mires. Additionally tree/shrub removal can be considered.

- Hand pulling is an effective method to remove small seedlings but disturbs the ground, which may then be seeded by neighbouring trees.

- Brush cutters and chainsaws can be used to clear established scrub manually. Both may cut into the peat without getting damaged, but the working position is complicated.

- Regrowth often occurs from dormant buds below or just above the soil surface. It is therefore important to cut the tree below the surface to reduce regrowth.

- Some species coppice when cut and require secondary treatments such as cyclical cutting, ring barking, grazing or flooding. Ring-barking will kill off the tree above the ring and may suppress resprouting stronger than felling.

- The use of herbicides should be avoided. Herbicides should only be used if absolutely necessary, e.g. to control invasive species. Herbicides can be applied directly to the leaves, applied to the trunk or painted onto the cut stump. Their use should be carefully controlled both for health and safety reasons and so as not to affect non-target species.

- In forestry plantations, the plough throws and ditches should be evened to bring more ground surface in contact with the water table.

- Woody material should be removed from the site. Leaving the brash on site can lead to localised enrichment, shading out of intolerant species and enhanced fire risk. When removal is impossible, the material may be spread, mulched, or used the backfill ditches or human-made open water bodies.

- Disposal of woody material by on site burning requires an emergency plan, optimal weather conditions (wet, not windy), a raised burning bin underlain by fire blankets or corrugated sheeting (to avoid contact with the peat soil), spades and beaters (in case the fire gets out of control), and the removal of the ash (as a concentrated fertiliser).

Restoration of open mire vegetation

About half of the degraded peatland area worldwide is formed by peatlands in agricultural use and partly (strongly) nutrient-enriched. For these lands three options exist with respect to rewetting and restoration: top soil removal, phytoextraction (cf. paludiculture), or accept hypertrophic fens with low biodiversity for decades or longer.

- Prescreening of depth profiles for biologically available phosphorous can show whether topsoil removal may be useful, and to what depth.

- The removed soil can be used for filling material nearby ditches.

- Chemical alternatives to lower P availability, such as the addition of iron, calcium or lanthanum-modified clay, have been shown to fail (Geurts et al. 2011).

In case the desired species do not establish spontaneously, re-introduction can be considered.

- Hay transfer involves mowing a donor fen site, when the desired seeds are ripe, yet still attached to the stalks, and transferring the 'hay' directly onto the restoration site. Several harvests through the season allow to include species with different flowering times.

- For those species that do not readily produce viable seed, the transfer of small (30 cm x 30 cm) turfs (with sufficient depth to include the rhizomes!) will help accelerate the re-establishment of fen species. Transplantation is best undertaken at the beginning of the growing season.

- In the case of planting, herbivory by geese and other wetland birds can be addressed by the use of netting or scarecrows.

- The Moss Layer Transfer Technique implies the active reintroduction of peatland plant species, especially peatmosses, combined with rewetting. The method involves: preparing the sector to be restored, collecting plant material from a donor site, spreading the plant material, spreading mulch as a protective cover, fertilizing, rewetting by blocking the drainage system, and monitoring the restored sectors. The method is extensively described in Quinty & Rochefort (2003) with enlarged chapters published in 2019 and 2020.

- A nurse crop is useful in sites with large expanses of bare peat, helps to stabilize the peat and provides shelter to newly establishing mosses. Nursery plants may include *Eriophorum*, *Carex* and *Polytrichum strictum*.

Restoring traditional management

Traditionally, many naturally open fens in Europe and Eastern-Asia were mown and grazed for fodder and litter (and often slightly drained). After use was abandoned, these fens suffer under heavy losses in typical species diversity, a decrease in bryophyte cover, a dominance of some graminoid species, and tree and shrub encroachment.

The former vegetation can be restored through intensive mowing, e.g. twice-a-year instead of traditional late annual mowing. This may, however, also lead by the destruction of microtopography to a loss of fen specialists and red listed species and enhance acidification. Preference should therefore be given to restoring pre-exploitation hydrologic conditions, if still possible (see Ramsar Technical Report).

Author

Hans Joosten
Greifswald University and Duene e.V., Partners in the Greifswald Mire Centre, Greifswald

Citation (Secretariat to complete).

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In 2019 and 2020, Chapter 4 was revised and republished in independent booklets;
Planning Restoration Projects (replace pp. 13 to 24 in the 2003 Guide)
Site Preparation and Rewetting (replace pp. 25 to 35 and pp. 60 to 62)
Plant Material Collecting and Donor Site Management (replace pp. 36 to 45)
Spreading of Plant Material, Mulch and Fertilizer (replace pp. 46 to 59)

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