Global Peatland Restoration

Manual

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Introduction

The following document presents a science based and practical guide to peatland restoration for policy makers and site managers. The work has relevance to all peatlands of the world but focuses on the four core regions of the UNEP-GEF project "Integrated Management of Peatlands for Biodiversity and Climate Change": Indonesia, China, Western Siberia, and Europe.

Chapter 1 *"Characteristics, distribution, and types of peatlands"* provides basic information on the characteristics, the distribution, and the most important types of mires and peatlands.

Chapter 2 *"Functions & impacts of damage"* explains peatland functions and values. The impact of different forms of damage on these functions is explained and the possibilities of their restoration are reviewed.

Chapter 3 *"Planning for restoration"* guides users through the process of objective setting. It gives assistance in questions of strategic and site management planning.

Chapter 4 *"Standard management approaches"* describes techniques for practical peatland restoration that suit individual needs.

Unless otherwise indicated, all statements are referenced in the IPS/IMCG book on Wise Use of Mires and Peatlands (Joosten & Clarke 2002), that is available under http://www.imcg.net/docum/wise.htm

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1 Characteristics, distribution and types of peatlands

1.1 Peatland characteristics

In those wetlands where the water level is stable near the surface (just below, at, or just above), the remains of dead plants and mosses do not fully rot away. Under conditions of almost permanent water saturation and consequent absence of oxygen they accumulate as *peat*. A wetland in which peat is actively accumulating is called *mire*. In most mires, the process of peat accumulation continues for thousands of years so that eventually the area may be covered with meters thick layers of peat. An area of land with a soil of peat is called a *peatland*.

Undrained peat contains between 85 % and 95 % of water, and can be regarded as “a mass of water wrapped up in some organic material”.

Terms and concepts

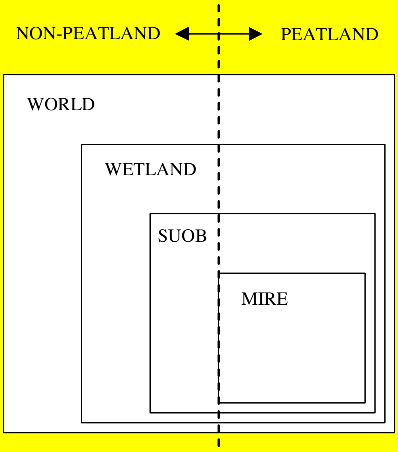
A **wetland** is an area that is inundated or saturated by water at a frequency and for duration sufficient to support a prevalence of vegetation typically adapted for life in saturated soil conditions.

Peat is an accumulation of dead organic material that has been formed on the spot and has not been transported after its formation. It differs in this respect from organic sediments (like gyttjas and folisols), where the organic material originated in a place other than as where it was deposited.

A **peatland** is an area (with or without vegetation) with a naturally accumulated peat layer at the surface.

A **mire** is a peatland where peat is currently being formed. Mires are wetlands, as peat is largely formed under waterlogged conditions. Peatlands, where peat accumulation has stopped, are no longer mires.

A **suob** is a wetland with or without a peat layer dominated by vegetation that may produce peat.



The relation between various peat-related concepts

Crucial for understanding peatlands is the awareness that in peatlands “plants”, “water”, and “peat” are very closely connected and mutually interdependent (Fig. 1). The plants determine what type of peat will be formed and what its hydraulic properties will be. The hydrology determines which plants will grow, whether peat will be stored and how decomposed the peat will be. The peat structure and the relief determine how the water will flow and fluctuate.

These close interrelations imply that when any one of these components changes, the others will change too. Not necessarily at once, but in the longer run inevitably…

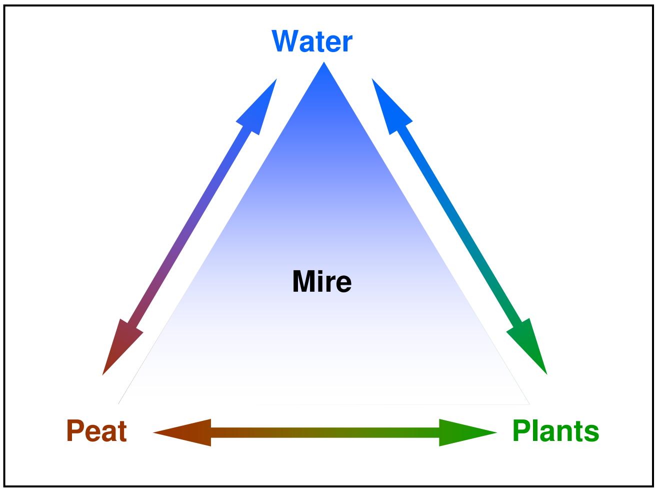


Fig. 1: The interrelations between plants, water and peat in a mire

The presence of peat, the permanent water logging, and the continuous upward growth of the surface are the major characteristics of mires.

The organisms that live in mires are adapted to the special and extreme site conditions that prevail, including

- The high water level and the consequent scarcity of oxygen and the possible presence of toxic ions (Fe^{2+}, Mn^{2+}, S^{2-}) in the root layer
- The continuous peat accumulation and rising water levels which suffocates perennial plants
- The often spongy soil, that makes trees easily fall over or drown under their own weight
- The scarcity of nutrients as a result of peat accumulation (by which nutrients are fixed in the peat), limited supply (as in rainwater-fed mires) or chemical precipitation (as in groundwater-fed mires, where phosphates are bound by calcium, iron and humic substances). Scarcity of ions in the mire water furthermore complicates osmoregulation in submersed organs and organisms
- The generally cooler and more humid climate than on the surrounding mineral soils, with strong temperature fluctuations
- The acidity caused by cation exchange and the abundance of organic acids
- The presence of toxic organic substances produced during decomposition and humification (i.e. the breakdown and alteration of organics material)
- The humus rich 'black' water, complicating orientation and recognition in aquatic animals.

As a result of these extreme conditions, mires are in generally species poor when compared to mineral soils in the same biographic region. Many mire species are, however, strongly specialised and not found in other habitats.

1.2 Peatland distribution

Because of the necessary water saturation, peat formation strongly depends on climatic and topographic conditions. Mires are especially abundant in cold areas, i.e. the boreal and sub-arctic regions, and in wet regions, i.e. in oceanic areas and in the humid tropics. They prevail on flat land areas, such as western Siberia, the Hudson Bay Lowlands (Canada), the SE Asian coastal plains, and the Amazon Basin (see Fig. 2).

Peatlands are found in almost every country of the world (see the IMCG Global Peatland Database: www.imcg.net/gpd/gpd.htm). In total 4 million km^2 on Earth (some 3 % of the land area) is covered with peatland.

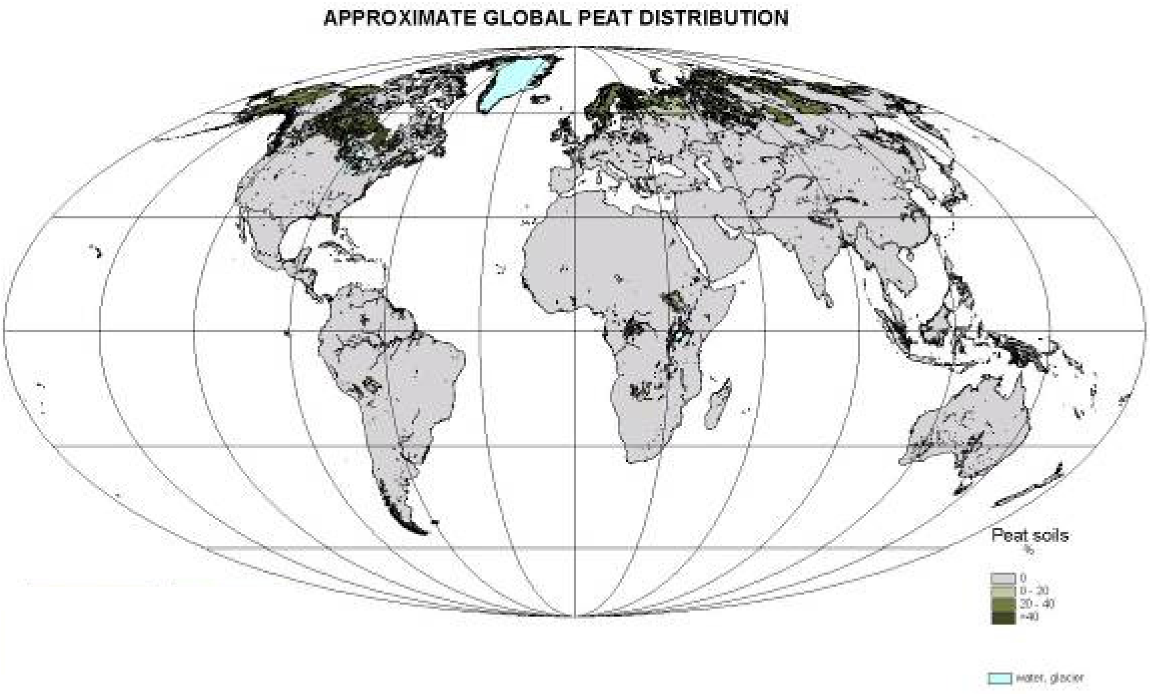


Fig. 2: Approximate global peatland distribution

1.3 Peatland types

There are many ways of classifying peatlands that vary according to the purposes of the classification.

Classically peatlands are classified into **bogs** that lay higher than their surroundings ("high mires") and **fens** in landscape depressions ("low mires") (Fig. 3).

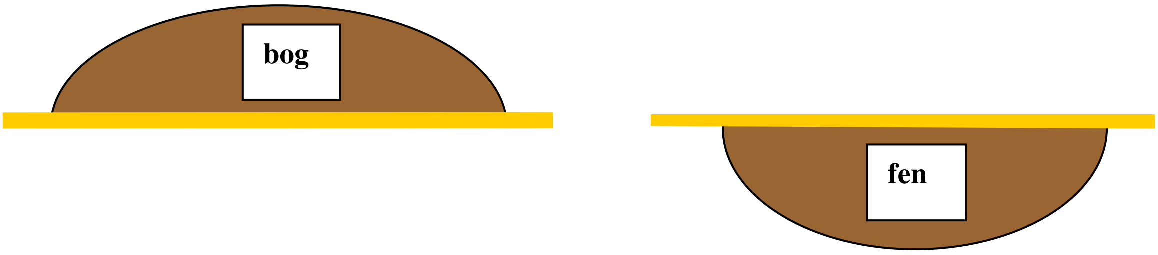


Fig. 3: The historical difference between "bog" and "fen"

This largely parallels the modern division in **ombrogenous mires** that are fed only by precipitation (rain, snow) and **geogenous mires** that are also fed by water that has been in contact with mineral soil or bedrock.

Precipitation water is poor in nutrients and somewhat acid. Through contact with the mineral soil/bedrock the chemical properties of the water change.

As a result, peatlands in different situations receive very different qualities of water. Especially the acidity (base saturation) and the nutrient availability (trophic conditions) of the water strongly determine which plant species will grow in the mire. This is the basis for the distinction of **ecological mire types** that differ from each other with respect to acidity, trophy, and characteristic plant species (Table 1, Fig. 4).

Table 1: Ecological mire types and their pH characterization after (Sjörs 1950)

Peatland type	**pH range**
bog	3.7 – 4.2
extremely poor fen	3.8 – 5.0
transitional poor fen	4.8 – 5.7
intermediate fen	5.2 – 6.4
transitional rich fen	5.8 – 7.0
extremely rich fen	7.0 – 8.4

The pH trajectories (see Table 1) are largely determined by chemical buffer processes and therefore probably have a worldwide validity.

It should be noted that the terms "poor" and "rich" in Table 1 refer to the level of base-saturation (as indicated by pH), not to nutrient availability. It is wrong (but often practised!) to equal these terms with oligotrophic ("poorly fed") and eutrophic ("well fed"): extremely rich fens are often very poor in nutrients! The latter terms should be restricted to express nutrient availability and primary production, as inter alia indicated by the C/N (or N/C) ratio of the topsoil or by the C/N and P/N ratios in the plant material.

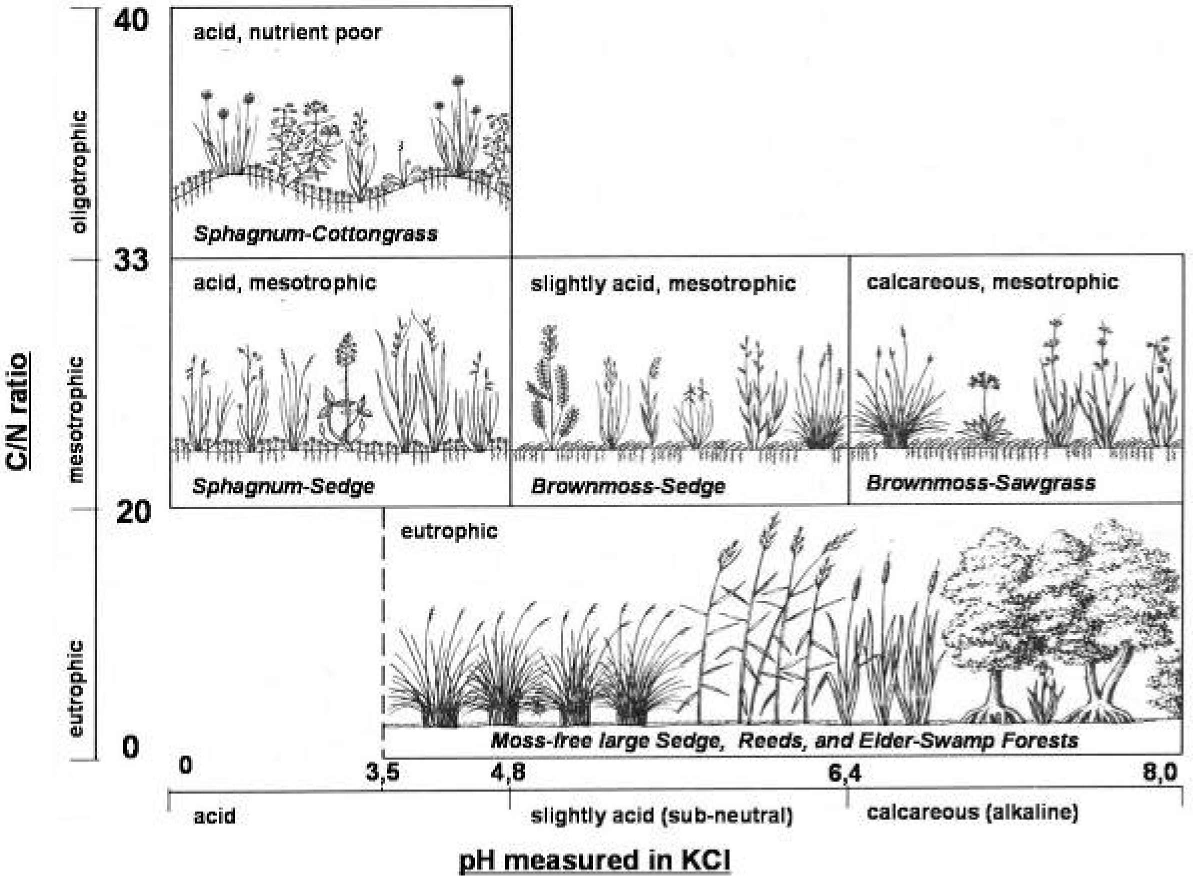


Fig. 4: Ecological mire types for Central-Europe (after Succow & Joosten 2001)

The ecological mire typology is especially relevant for species diversity and species conservation, because rare and threatened peatland plants mostly occur under carbonate-rich/subneutral and oligo-/mesotrophic conditions (mostly with P limitation, see Wassen et al. 2005). The dependence of these local mire conditions on the quality of the incoming groundwater necessitates a thorough assessment of the hydrological relations with the surroundings (see also chapter 3.3).

Where the ecological mire typology focuses on the resulting site conditions (i.e. is more descriptive), a second important mire typology, the **hydrogenetic typology**, deals more with the underlying processes (i.e. is more analytic). The latter typology considers the hydrological conditions of peat formation as well as the hydrological role of the mire in the landscape and is especially useful from a functional and management point of view (see Succow & Joosten 2001).

Classically a distinction is made between **terrestrialisation**, when peat develops in open water, and **paludification**, when peat accumulates directly over a formerly dry, paludifying mineral soil (Fig. 5).

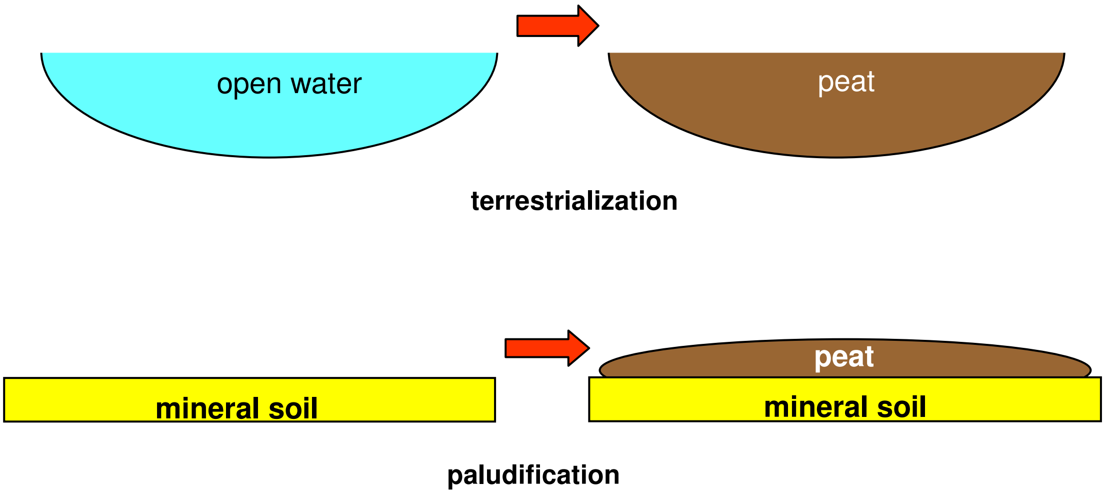


Fig. 5: The difference between terrestrialization and paludification

The modern hydrogenetic typology distinguishes two main groups of mires (Table 2):

1. In **horizontal mires** the water level forms a horizontal plane in a closed basin. The water movement is largely vertical (*water level fluctuations*) and the water level of the mire only passively follows the water level of the surrounding catchment.

2. In **sloping mires** the water level forms an inclining plane and the water movement is mainly horizontal (*water flow*). The laterally flowing water is retarded by vegetation and peat. Vegetation growth and peat accumulation thus cause a rise of the water table in the mire and often also in the catchment area.

Table 2: Overview of hydrogenetic mire types

Horizontal mires		**Sloping mires**
Schwingmoor	terrestrialisation mires	Percolation mires
Immersion		
Water rise mires		Surface flow mires
Flood mires		Acrotelm mires

The most common horizontal mires are **terrestrialization mires**, formed by peat formation in ‘open’ water. They can be subdivided into **schwingmoor mires** (floating mats, e.g. *Papyrus* islands) and **immersion mires** in which peat accumulates underwater on the bottom (e.g. many *Phragmites* stands) (Fig. 6).

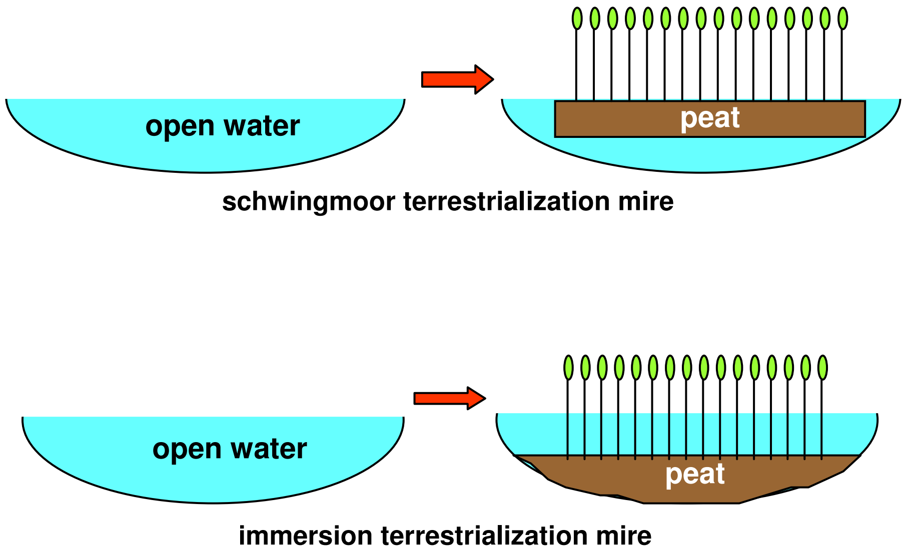


Fig. 6: The two subtypes of terrestrialization mires

Water rise mires originate when the water level in the catchment rises so slowly that a formerly dry depression becomes wet, but no open water (lake, pool) is formed (Fig. 7). A rise in groundwater level may be caused by an increase in water supply (by changes in climate or land use) or a decrease in water losses (by sea level rise, beaver dams, the origin of stagnating layers in the soil, etc.).

Flood mires are periodically flooded by rivers, lakes or seas. They also originate and persist under conditions of rising water levels (rising sea water level, rising river beds, etc.). As such they are related to water rise mires (cf. Fig. 7). The difference is the mechanical action of periodic lateral water flow and associated sedimentation of allogenic sand and clay.

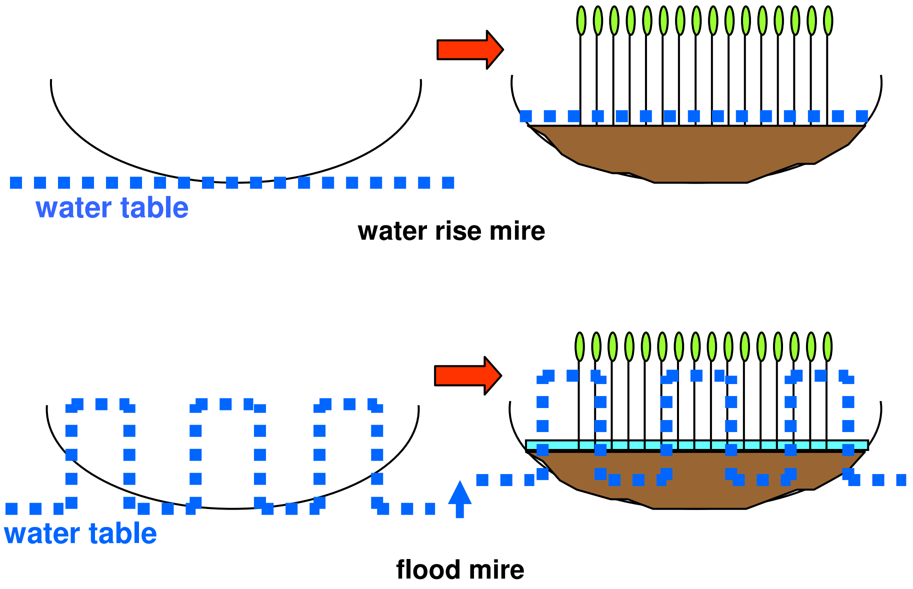


Fig. 7: Water rise and flood mires - a result of externally induced water level rise

Sloping mires are found as percolation, surface flow, and acrotelm mires.

Percolation mires are found in areas where the water supply is large and evenly distributed over the year. The weakly decomposed or coarse peats are highly permeable and the water flows via a considerable part of the peat body (see Fig. 8).

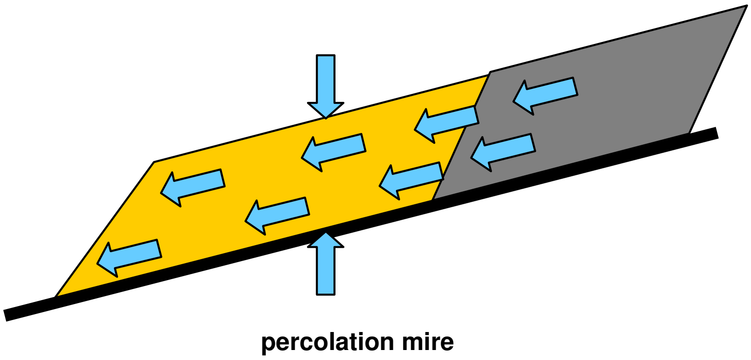


Fig. 8: In percolation mires water flows through the peat body

Percolation mires are normally groundwater-fed mires, because only large catchment areas can guarantee a large and continuous water supply in most climates. In constantly humid climates also ombrogenous percolation mires exist, such as the *Sphagnum*-dominated mires of Kolchis (Georgia) and the swamp forest bogs of SE Asia.

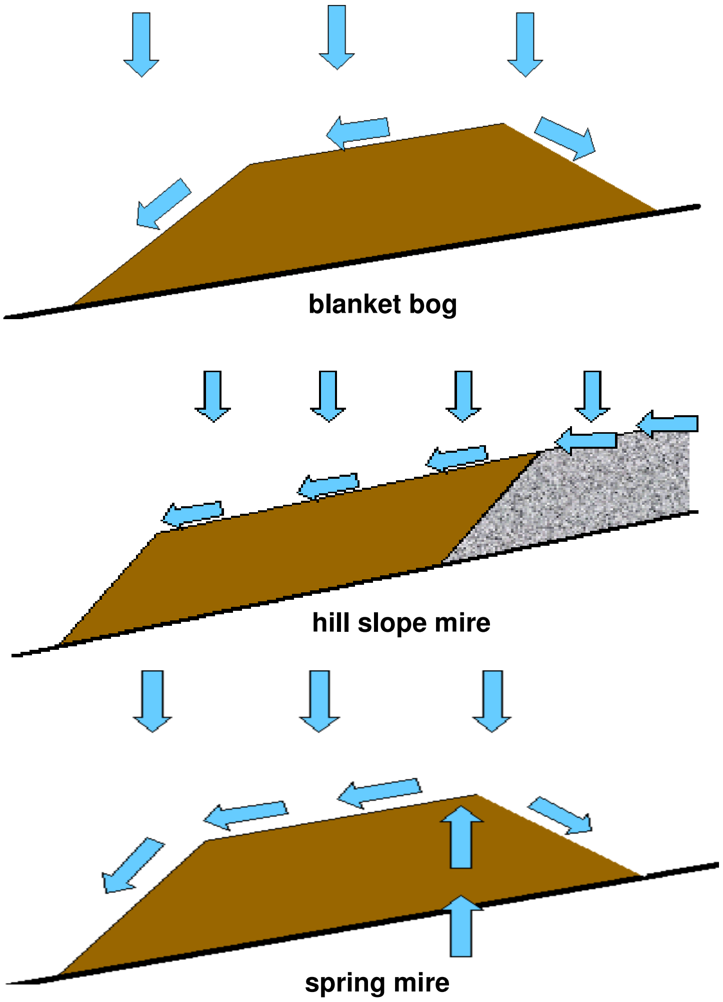


Fig. 9: In surface flow mires water flows over the peat body

Surface flow mires are found where the ample water supply is regular but exceeded by water losses (through evapotranspiration and run-off) during short periods. During these short events oxygen penetrates the peat. The resulting stronger decomposition and compaction makes the peat less permeable and forces the water eventually to overflow the mire surface (Fig. 9). Because of the low hydraulic conductivity of their peats and the large water supply, surface flow mires can occur on and with steep slopes.
Three subtypes of surface flow mires can be distinguished (Fig. 9): *Blanket bogs* only occur under very oceanic conditions and cover the lands like a blanket, i.e. regardless of the relief. They are solely fed by rainwater. *Hill slope mires* are additionally fed by (near-)surface run-off from the surrounding mineral slopes. S*pring mires* occur where artesian groundwater exfiltrates; their peats often includes carbonates, iron ore, and silicates that have precipitated from or washed in with the groundwater.

Acrotelm mires occupy an intermediate but very special position. The plant material they produce is very resistant against decay and the top decimetres of the peat is consequently little decomposed. Water flow is largely confined to these top layers (Fig. 10). The distinct gradient in hydraulic conductivity in the top layers (Fig. 11), combined with its large storage capacity, constitutes a very efficient water level regulation device, the so-called *acrotelm*. In times of water shortage, the water level drops into a less permeable range and run off is retarded. Evapotranspiration then still leads to water losses, but because of the large storage coefficient of the peat, the water level drops only to a small extent.

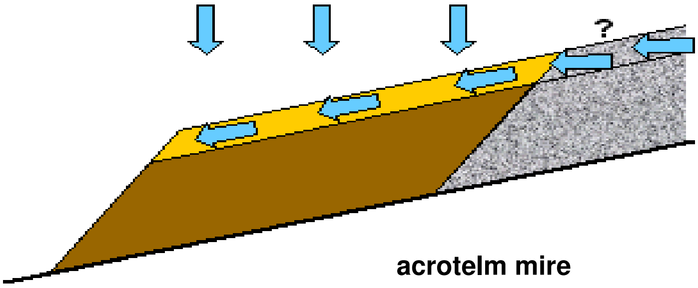


Fig. 10: In acrotelm mires most water flows through the uppermost peat layers

Globally the *raised bog* is the only acrotelm mire type so far identified. In the raised bogs of the northern hemisphere, only a few (hummock and lawn building) *Sphagnum* species (*S. fuscum*, *S. rubellum/capillifolium*, *S. magellanicum*, *S. imbricatum*, and *S. papillosum*) can build an effective acrotelm. The global distribution of raised bogs, far beyond the area where percolation and surface flow mires may exist, illustrates the effectiveness of the acrotelm regulation mechanism. The tropical peatswamps of Southeast Asia are also acrotelm mires. In these mires the acrotelm is largely constituted by the vegetation (lowermost tree stems/roots) and litter (Joosten 2008).

The hydraulic conductivity and water level characteristics of these three types of sloping mire are presented in Fig. 11.

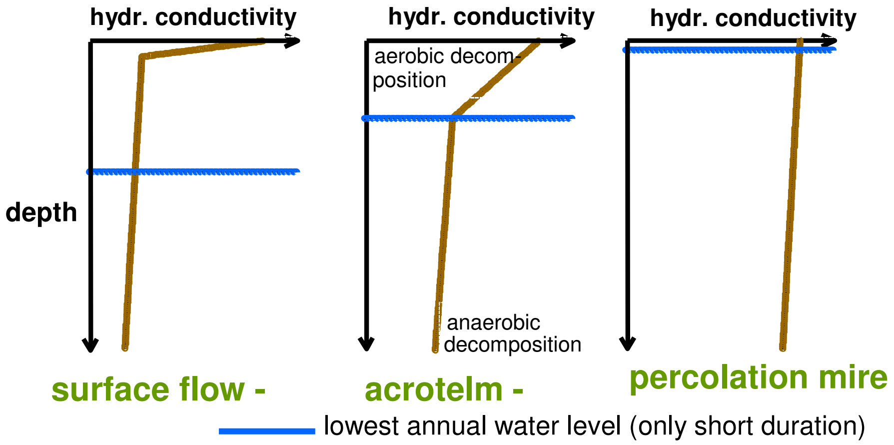


Fig. 11: Hydraulic conductivity and water level characteristics of sloping mires

As a result of water, vegetation, and peat interacting over extensive time ("self-organisation") various **morphological types** of mires with typical shapes and surface patterns develop, such as plateau bogs, concentric bogs, eccentric bogs, and aapa fens (see about their origin Glaser 1999, Couwenberg & Joosten 2005, Couwenberg & Joosten 1999).

Also external mechanisms may be important in the configuration of peatland macro- and micro-patterns. Of special importance is ice formation in the arctic, subarctic and boreal zones, that may give rise to specific morphologic peatland types, such as the "polygon mires" in areas with continuous permafrost and the "palsa" (frost mound) and "peat plateau" mires in areas of discontinuous permafrost.

2 Peatland functions and impacts of damage

Restoration is the process of bringing something back what you have lost[1].

In order to restore you have to know

1. what you would like to have back
2. whether it is possible to get it back
3. what you have to do to get it back

The first question relates to functions: which valuable products or services did the damaged peatland formerly provide?
The second question relates to disturbances: which relevant properties of the peatland have been disturbed and have any irreversible changes taken place?
The third questions relates to methods: which techniques must be applied to restore the relevant peatland functions?

2.1 Peatland degradation stages

In chapter 1.1 (Fig. 1) we have seen, that in a peatland/mire strong interrelationships exist between 'plants', 'water', and 'peat': when one component is affected, eventually all components will change.
Although these components are thus closely interconnected, they do not react in a similar way. Generally organisms are more easily affected (e.g. by cutting and hunting) than hydrology (e.g. by ditching and pumping) and hydrology again much easier than the peat body. Metaphorically speaking, we can call peat a more 'heavy' component than plants: it is more difficult to get it in motion, but when it is moving, it is more difficult to stop and to reverse the change.
Therefore it is useful to distinguish peatland degradation stages according to the 'heaviness' of the components affected (Table 3).

As a general rule, components that are more difficult to affect are also more difficult to restore. When only the vegetation has been damaged, but the hydrological conditions have remained unaffected (degradation **stage 1** 'minor', Table 3), restoration is simple: as soon as the disturbing factor has been removed, the mire will regenerate spontaneously, provided that sufficient diaspores of the key plant species are available. The same accounts for **stage 2** ('modest') after recovery of the recently changed hydrology. Examples of the latter are the spontaneous regeneration of buckwheat fire cultivation fields in Northwestern Germany (Joosten 1995) or of afforested peatlands on the German-Czechian border (Edom 2001) after collapse or overgrowing of the drainage ditches.

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[1] Synonyms for restoration include rehabilitation, restitution, reconstruction, revitalisation, remediation, etc. Restoration is where actions are taken to assist regeneration. Regeneration is the spontaneous re-development to a state as existed before disturbance.

Table 3: Peatland degradation stages

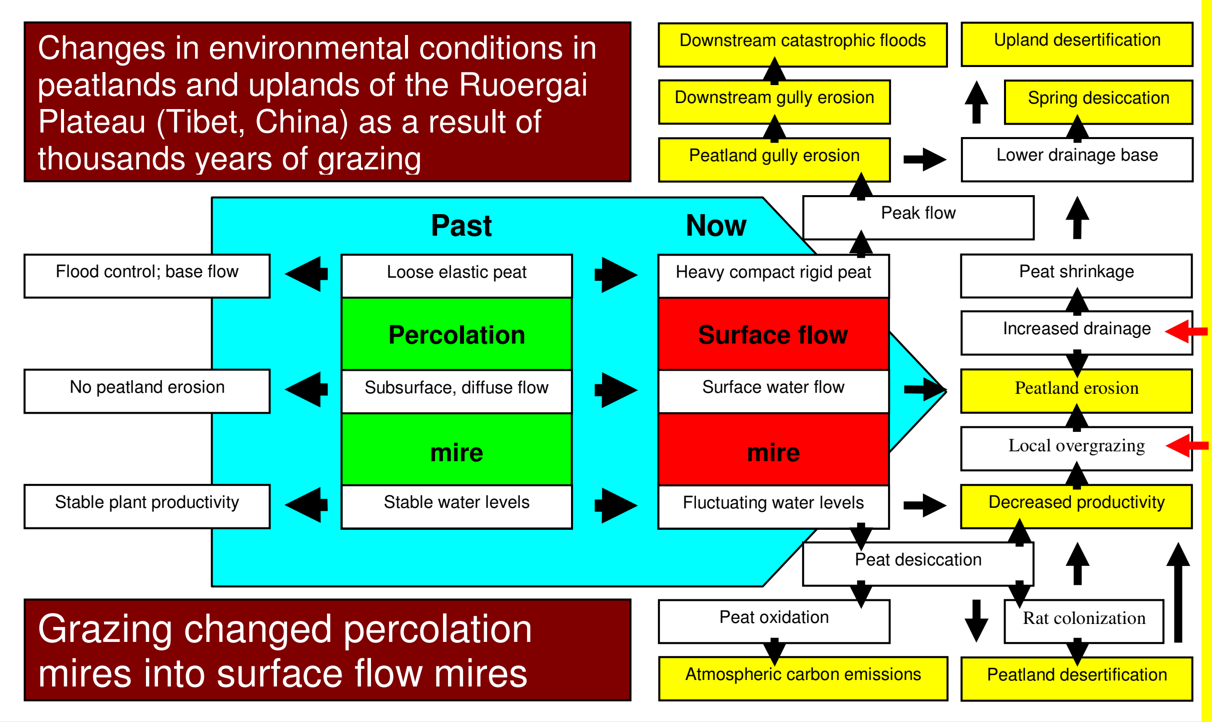
	Peatland components							
	plants		water		peat			
Degradation stage	Fauna / flora	Vegetation	Hydrology	Soil hydraulics	Form and relief	Peat deposits	**Site characteristics**	Peat accumulation rate
0. Minimal	🟩 🟨	🟩	🟩	🟩	🟩	🟩	Natural spontaneous vegetation: undrained, human impact restricted to hunting/ gathering; possibly some change in flora and fauna	> 0 (≤ 0)
1. Minor	🟨	🟨	🟩	🟩	🟩	🟩	Change in vegetation because of low-intensity grazing/mowing or forestry; not/slightly drained; no pedogenesis	> 0 (≤ 0)
2. Modest	🟨	🟨	🟨	🟩	🟩	🟩	Freshly deeply drained; spontaneous vegetation changed through recent drainage or regular harvesting; no pedogenesis yet	≤ 0
3. Moderate	🟨	🟨	🟨	🟨	🟩	🟩	Long-term very shallow drainage; some pedogenesis; spontaneous vegetation changed by long-term use; paludiculture	≤ 0 (> 0)
4. Major	🟥	🟥	🟥	🟥	🟨	🟩	Long-term deeply drained or inundated, strong pedogenesis; peatland form modified by subsidence and oxidation	< 0 - << 0
5. Maximal	🟥	🟥	🟥	🟥	🟥	🟥	Intensively drained; strong pedogenesis or compact peats surfacing; peat body severely affected by peat erosion, oxidation or extraction	<< 0 - <<<0
	increasing degradation ➡ **decreasing restorability**							

🟩	Not -	🟨	Slightly -	🟥	Severely affected

In **stage 3** ('moderate') the situation becomes more complicated. This stage represents peatlands (especially percolation and acrotelm mires) where long lasting utilisation has changed the soil hydraulic properties but peat accumulation has continued. Examples are the mires in the Biebrza valley (NE-Poland) and on the Ruoergai Plateau (Tibet, China) where many centuries of low-intensity mowing and grazing have lead to the accumulation of newly grown, more compact peats over the originally loose percolation peats. In the Biebrza the resulting larger water level fluctuations, after the recent cessation of mowing, stimulate the establishment of scrubs and woodland on the originally open mires. Furthermore the formation of 'rainwater lenses' in the less permeable peat leads to acidification and the loss of rare species of calcareous habitats (Schipper et al. 2007). In Tibet the change in peat type has lead to a complete change from percolation mires to surface flow mires that are much more sensitive to overgrazing and erosion (Schumann & Joosten 2007). A repair of the water regime of the original percolation mires is tedious and requires long-lasting sophisticated management or even the removal of the uppermost compact peat layers over large areas.

Peatland degradation on the Tibetan Plateau (China)

Thousands year of grazing with yaks and sheep, in combination with the deposition of clastic erosional products from the overgrazed hills, have lead to a compaction of the peat layers on the Tibetan Plateau (China). As a result the peat has become largely impermeable and the water that formerly flew through the whole peat body ("percolation mires") is now forced to flow over the surface ("surface flow mires"), which leads to a whole range of environmental impacts.



Similar changes in soil hydraulics may take place as a result of other processes. Peatlands in areas with much **nitrate or sulphate input** suffer from increased oxidation by these oxidants (that also function under wet conditions) which lead to a stronger compaction of the peat. The latter has been a cause for the degradation of non-drained mires in the Czechian mountains through air pollution.

Many peatlands in highly populated areas find themselves in degradation stages 4 ('major') or 5 ('maximal'). **Stage 4** represents peatland of which the peat is irreversibly degraded by long-term drainage or where a strongly decomposed peat is surfacing as a result of peat mining. Percolation and acrotelm mires require the hydraulic propertied of non- or little humified peats to regulate their hydrology. Because of the slowness of peat growth, it may take tens to (many) hundreds of years to re-install new peat deposits with the right properties.

Degradation **stage 5** includes peatlands that have lost so much peat by mining, erosion or oxidation that the peatland body has got completely out of hydrological balance. Locally and temporally value biocoenoses can still be conserved or restored, but restoration of a self-regulating mire has become impossible.

But eventually all peatland components influence each other.

The mire landscape components (Table 3) influence each other in two directions. Modification of the peatland's hydrology, for example, will directly affect the area's flora and fauna. On the longer run changes in the hydrology will also impinge on the hydraulic soil properties, on the relief, and eventually on the composition and the mere existence of the peat body, even when these are not directly damaged in first instance. Unlike sand, peat is not an inert but a dynamic substance.

The degradation stages therefore differ fundamentally from each other. A further degradation stage does not only imply a more intense modification of the same components, but also a qualitative jump to a more "heavy" stage, i.e. a more important component for mire functioning.

For this reason more degraded peatlands are more difficult to restore. They require explicit attention to components that might not have been directly impacted, but that have degraded as the longer-term but inevitable result of degradation of other components. In general peatland restoration should start with restoring the "heaviest" components, i.e. those with the strongest long-term impact (the ones further to the right in Table 3) because these determine also the condition of the weaker components (those further to the left).There is, for example, little sense in replanting peatland/wetland vegetation, when the damage to hydrology has not yet been repaired.

2.2 Peatland functions

The products and services (“functions”, see Table 4) that mires and peatlands provide are manifold.

They have been extensively reviewed in the book “The Wise Use of Mires and Peatlands” (available under http://www.imcg.net/docum/WUMP_Wise_Use_of_Mires_and_Peatlands_book.pdf).

Table 4: Overview of peatland functions (products and services that peatlands provide) (modified after Joosten and Clarke 2002).

Function		**Examples**
1. Production		Providing water, food, raw materials, energy, labour
2. Carrier		Providing space and substrate for habitation, cultivation, energy generation, conservation, recreation
3. Regulation		Regulating climatic, water, soil, ecological, and genetic conditions
4. Information	4a. social amenity	Providing company, friendship, solidarity, cosiness, respect, home
	4b. recreation	Providing opportunities for recreation, recuperation, stress mitigation
	4c. aesthetic	Providing aesthetic experience (beauty, arts, taste)
	4d. signalisation	Providing signals (indicator organisms, status, monetary price, taste)
	4e. symbolisation	Providing embodiments of other functions (mascots, status symbols)
	4f. spirituality	Providing reflection and spiritual enrichment (religion, spirituality)
	4g. history	Providing notions of cultural continuity (history, heritage, ancestors)
	4h. existence	Providing notions of ecological and evolutionary connectedness
	4i. cognition	Providing satisfaction of curiosity, science
5. Transformation (= education)		Providing a change of preferences, character building
6. Option (= bequest)		Providing insurance, heritage

Some of the functions can only be performed by pristine mires; others can also or even only be executed by peatlands that are modified by human action.
Some functions are sustainable, i.e. they can be exploited infinitely; others destroy their own peatland resource base and can only be provided for a limited period.

Table 5 relates the major functions of a peatland to the required or resulting quality state of the peatland. Further specification of functions may narrow down the peatland quality states that provide that concrete function.

Table 5: Sustainability of peatland functions and their required or provoked quality. For disturbance classes, see Table 3. For further backgrounds of the functions, see Joosten & Clarke (2002). The sustainability of the functions is related to the peatland character: we consider, for example, peatland forestry as sustainable when it sustains the peat deposit, not when the peat body is oxidized by continuing forestry.

		degradation ← → restoration					
		Peatland degradation stage					
	Peatland functions	0. minimal	1. minor	2. modest	3. moderate	4. major	5 maximal
Production functions:							
🟪	Peat extracted and used ex situ	🟥	🟥	🟩	🟩	🟩	🟥
🟦	Drinking water	🟩	🟩	🟥	🟩	🟥	🟥
🟦	Wild peatland plants	🟩	🟩	🟩	🟩	🟥	🟥
🟦	Wild peatland animals	🟩	🟩	🟩	🟩	🟥	🟥
🟦	Wet peatland agri- and horticulture (paludiculture)	🟥	🟥	🟥	🟩	🟥	🟥
🟪	Drained peatland agri-and horticulture	🟥	🟥	🟥	🟩	🟩	🟥
🟦	Transitory collection peatland forestry	🟩	🟩	🟩	🟩	🟥	🟥
🟦	Conserving management forestry	🟥	🟩	🟩	🟩	🟩	🟥
🟪	Progressive management forestry	🟥	🟥	🟩	🟩	🟩	🟥
Carrier functions:							
🟪	Space	🟩	🟩	🟩	🟩	🟩	🟩
Regulation functions:							
🟦	Long-term carbon sequestration (global climate)	🟩	🟩	🟥	🟩	🟥	🟥
🟦	Long-term carbon storage (global climate)	🟩	🟩	🟥	🟩	🟥	🟥
🟦	Short-term carbon sequestration / storage (global climate)	🟥	🟩	🟩	🟩	🟥	🟥
🟦	Transpiration cooling in warm and dry climates	🟩	🟩	🟥	🟩	🟥	🟥
🟪	Radiation cooling in boreal zones	🟥	🟥	🟩	🟥	🟩	🟩
🟦	Flood control and guaranteed base flow	□	□	🟩	□	🟥	🟥
🟪	Emission of C, N, and P to surface waters	🟥	🟥	🟩	🟥	🟩	🟩
🟦	Groundwater denitrification	🟩	🟩	🟩	🟩	🟥	🟥
🟦	Surface water reduction of B.O.D., solids, P, and N	🟩	🟩	🟥	🟩	🟥	🟥
Informational functions:							
🟦	Social amenity, employment	🟩	🟩	🟩	🟩	🟩	🟥
🟦	History, identity	🟩	🟩	🟩	🟩	🟩	🟩
🟦	Peatland recreation	🟩	🟩	🟩	🟩	🟥	🟥
🟦	Peatland aesthetics	🟩	🟩	🟩	🟩	🟥	🟥
🟦	Symbolisation, spirituality, and existence	🟩	🟩	🟩	🟩	🟥	🟥
🟦	Cognition	🟩	🟩	🟩	🟩	🟩	🟩
🟦	Signalisation	🟩	🟩	🟥	🟩	🟥	🟥
🟦	Transformation/education	🟩	🟩	🟩	🟩	🟩	🟩
🟦	**Option functions**	🟩	🟩	🟩	🟩	🟥	🟥

🟦	potentially sustainable	🟪	unsustainable	🟩	compatible with this class	□	type dependent	🟥	incompatible with this class

Below we give an overview of the major peatland functions and their restoration perspectives.

Production functions

Peat extraction generally leads to moderate or major disturbance. Only peat extraction in (small) pits without substantial drainage and the limited subsurface winning of "sausage peat" may lead to peatland with minor disturbance. Restoring a peatland for future peat extraction (after re-instalment of peat accumulation) is conceivable but has not yet been implemented because of the long time needed to regrow a commercially extractable volume of peat. See also *Carbon sequestration*, which also depends on peat accumulation.

The provision of good quality *drinking water* is generally limited to peatlands with little drainage and human use. More disturbed sites lead to overloading of the water with peat particles, humus acids, and nitrogen and the water quality rapidly decreases.

Wild *mire plants and animals* can by definition only be harvested from non- or slightly degraded or adequately restored locations. Wild *peatland plants and animals* can also be harvested from modestly degraded (i.e. drained) peatlands.

Wet agri- and *horticulture* (paludiculture, e.g. reed, Sphagnum, Sago or Jelutung cultivation, Wichtmann & Joosten 2007) focus on moderately disturbed peatlands (incl. major disturbed peatlands after rewetting). *Drained peatland agri-* and *horticulture* require at least major disturbed peatlands.

Forestry may take place in various intensities on various peatland degradation types. Simple harvesting ("transitory collection") may take place from both undrained and slightly drained peatlands. Other forms of forestry are associated with stronger impact (drainage, planting, fertilizing).

Carrier functions

The provision of *space* for all kinds of purpose is not bound to specific peatland degradation types.

Regulation functions

Long-term carbon sequestration is a function explicitly restricted to active peat accumulating systems, i.e. to minimally, minor and moderately disturbed mires. Peat accumulation is only possible when the water level in the peatland is - on average in the long-term - near the surface. The exact level depends on the peatland type. Both too low and too high water levels are detrimental to peat accumulation and the associated functions.
Long-term carbon storage in the peat is a function performed by all peatlands where peat is still available. The carbon storage of the peatland, however, decreases with the degree of disturbance. Furthermore also the biomass Carbon store of the existing vegetation must be taken into account. *Short-term carbon sequestration and storage* through increased biomass takes place in case of peatland drainage in the boreal zone.

Transpiration cooling in warm and dry climates is brought about by evapotranspiration of wet peatlands and therefore bound to minimally to moderately disturbed sites. In contrast, regional *radiation cooling* in colder climate zones happens after peatland drainage.

Flood control and guaranteed base flow are functions restricted to specific types of mire and degradation stages. As peat accumulation requires high water levels during most of the year, the available storage capacity in little disturbed mires is rapidly filled up and the surplus water drains quickly in times of abundant water supply. Minimally to moderately disturbed peatlands therefore generally show peak discharge, directly related to precipitation, and little base flow. Only mire types of which the peat layer can shrink and swell with changing water supply ("mire breathing") or that can store a large quantity of water at the surface (e.g. in hollows and pools) have a "buffering" effect on catchment hydrology.
After drainage, peak discharge is strongly reduced because the peat layer is no longer completely saturated. Intensively drained peatlands and severely degraded peat soils, on the other hand, will increase peak charge rates again. Restoring the flood control function therefore requires critical awareness of the hydrological conditions.

Depending on the character of the peatland, degraded peatlands may have a substantial *emission of C, N, and P* to the surrounding surface waters. This does not apply to sites where peat is still accumulating. *Groundwater denitrification* takes place as long as Nitrate enriched groundwater gets into contact with saturated (anaerobic) peat. *Reduction of organic matter (B.O.D.), solids, P, and N* is a function of wet peatland vegetation receiving surface water and therefore restricted to non-and little disturbed sites.

Social amenity and *employment* can be provided by all peatlands, with somewhat limited possibilities in case of pristine peatlands. Also *history* and *identity functions* are not restricted to specific degradation stages. *Peatland recreation* and *aesthetics* are more concentrated on less disturbed sites. This accounts in even stronger degree for the *symbolisation*, *spirituality*, and *existence* functions.

The *cognition functions* of mires and peatlands provide opportunities for the development of knowledge and understanding. The palaeoecological archive value is typical for peatland; this value generally decreases with increasing degradation. Archive values can not be restored: when they are gone, they are gone forever.
Another important cognition aspect is biodiversity. The highest biodiversity values (both species and ecosystem biodiversity) are connected to the least disturbed sites. In some cases also slightly drained and exploited peatlands may have a high biodiversity value, e.g. in case of species rich meadows and hayfields.

Signalisation is the function of acting as a signal or indicator. As accumulating ecosystems, mire ecosystems have an important signalisation value. As wildernesses that have been spared from direct human activities for a long time, unmanaged mires offer valuable "zero" references to the effects of human interference.
Special adaptations of mire plants to acquire the necessary nutrients make these plants useful as environmental indicators, e.g. *Sphagnum* species as indicators of atmospheric pollution.

3 Planning for restoration

Peatland restoration comprises all deliberate action that initiates or accelerates the recovery of a degraded peatland to a former, better state[2]. Restoration deals with three main questions (chapter 2):

1. What do you want to have back?
2. Is it possible to get that back?
3. What do you have to do to get it back: what measures are necessary to reach the restoration objective?

This chapter deals with the techniques to address these questions.

3.1 Defining the problem

The first step of any restoration project is to *define the problem*: what is wrong with the present situation? This requires the identification of the key processes (biological, hydrological and chemical) responsible for the observed changes by analysing the landscape components and their functioning (Table 6).

Table 6: Key components to assess the condition of peatlands. For further information: see Brooks & Stoneman 1997a, pp. 59-88 and 247-266, Wheeler & Shaw 1995b, pp. 136-147, Siuda 2002 and Edom 2007.

What?	**Why?**	**How?**	
		Desk studies	*Field studies*
Catchment topography	• Site location (distance to machinery, building material, plant material, work power, accommodation of workers) • Access (roads, water ways, stable ground) • Potential hazards (waste disposal sites, polluters) • Effects of adjacent land use • Ecological infrastructure	Topographic maps, aerial photographs, satellite images (http://earth.google.com http://maps.google.de/)	- Levelling - Surveying and mapping
Peatland topography	• Possible hazards (old peat cuttings, lakes, rivers) • Weirs, dams, buildings, machinery, areas of waste disposal	Topographic maps, aerial photographs, satellite images (http://earth.google.com http://maps.google.de/)	- Levelling - Surveying and mapping - Kite or balloon photography
Climate	• Expectable amount of precipitation • Periods of water surplus or shortage • High or low precipitation • Periods of frozen ground	- Meteorological data - Historical descriptions - Literature - Responsible authorities	- Measurement and monitoring - Interviews with locals - automatic weather station
Catchment geology	• Hydrogeology • Mineral substrate	- Geological maps - Geological Service	- Generally not feasible

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[2] By definition, it is not possible to *restore* an object to something it has never been.

Peatland stratigraphy	• Peat types / peat thickness • Peatland type and origin • Suitability of peat for construction and foundation	- Literature / survey reports	- Line transects with peat coring equipment.
Catchment relief	• Sources of water • Water flow paths • Drainage and erosion lines • Sources of pollutants	- Geomorphological maps - Digital elevation models	- Levelling
Peatland relief	• Water flow paths • Drainage and erosion lines	- Relief maps - Digital elevation models	- Levelling
Catchment hydrology	• Recent hydrological changes (drainage, groundwater extraction, land use changes) • Climate change	- Literature, survey reports - Land use reports (drainage, mining, forestry, agriculture - Responsible authorities	- Piezometers in line transects - Water levelling - Water flow and flux determination
Peatland hydrology	• Natural and anthropogenic drainage patterns • Water quality • Water budgets • Water levels	- Literature, survey reports - Land use reports (drainage, mining, forestry, agriculture) - Responsible authorities	- Piezometers in line transects - Water levelling - Water flow and flux determination
Catchment soils	• Trophic situation	- Soil maps - Responsible authorities	- Soil mapping
Peatland soils	• Hydraulic properties (conductivity, storage coefficient, capillarity)	- Soil maps - Responsible authorities	- Soil mapping
Catchment flora and fauna	• Metapopulations • Areas and species of special (conservation) interest • Change in species composition • Invasive species • Selection of key areas via bio-indication	- Literature, survey reports - Aerial photographs, satellite images (http://earth.google.com http://maps.google.de/)	- Species survey and documentation - Mapping, collecting, catching, hunting - Interviews with locals
Peatland flora and fauna	• Areas and species of special (conservation) interest • Invasive species • Bio-indication of site conditions	- Literature, survey reports - Historic photographs - Aerial photographs	- Species survey and documentation - Mapping, collecting, catching, hunting - Interviews with locals
Cultural patterns	• Historical and archaeological objects of conservation value	- Institutes of archaeology and local heritage - Literature, survey reports	- Inventory (see also topography)
(Former) catchment use	• Former tree coverage of surrounding uplands • Drainage or irrigation systems	- Literature, survey reports - Responsible authorities - Historical descriptions (photographs, paintings) - Aerial photographs	- Consultation of (former) land users - Analysis of fossils and macro-rests (palaeo-ecology)
(Former) peatland use	• Drainage or irrigation systems • Former land use (cutting, grazing, mowing, burning, fertilizing, chemical treatment)	- Literature, survey reports - Responsible authorities - Historical descriptions (photographs, paintings) - Aerial photographs	- Consultation of (former) land users - Analysis of fossils and macro-rests (palaeo-ecology)
Protection status	• Conservation status • Legal concerns	- Responsible authorities	- Generally not feasible

3.2 Setting the goals

Not all features of the original ecosystem have to be restored, the focus may well be on specific aims. These aims (i.e. which peatland functions have to be restored) have to be formulated clearly, in priority order, and concretely in order to:

- prioritize between conflicting aims (too often irreconcilable aims are formulated),
- identify adequate methods (different aims require different methods, see chapter 4),
- enable effective evaluation (unspecific aims can not be evaluated).

In order to set realistic objectives, you have to know what you *can* restore. Is it technically possible to re-install the desired functions or has restoration become impossible because of irreversible changes in the peatland itself (e.g. soil hydraulics, species loss) or in its wider surroundings (e.g. landscape hydrology, climate)?

The question *'can you restore?'* is, however, not only depending on scientific and technical potential (see chapter 4), but also on legal and societal constraints. This means that the process of *objective setting* not only requires technical knowledge, but also good insight in the other stakeholders' interests and plans.

First things first: limiting further degradation

The first goal in restoration is to limit further degradation. When active peat growth can not be re-installed, limiting further degradation is the highest goal that can be achieved.
A peatland without peat accumulation remains subject to peat degradation and oxidation, which eventually leads to the total disappearance of the peat, the peatland, and the peatland associated functions.
The primary method for limiting further degradation is to restore the original wetness as early and as good as possible.

3.2.1 Technical constraints

The technical feasibility of restoring specific peatlands functions strongly depends on the stage of degradation (cf. Table 3).
Least affected and most easily restorable are peatlands in which only ***flora*** or ***fauna***, i.e. specific typical peatland species, but not the other site conditions (esp. hydrology) have been disturbed, e.g. by poaching, over-collection or fire. Restoration of such sites only involves facilitating spontaneous re-colonisation of the species (e.g. by creating suitable vegetation gaps for establishment) or the re-introduction of diaspores (e.g. by seeding) or whole organisms (e.g. by planting). In most cases, however, species disappear not because of direct overexploitation but because of changes in site conditions.

As most peatland exploitation involves drainage (see Table 3), changes of the peatland's ***hydrology*** is the most common problem in peatland restoration. In mires, a change in mean water level of some centimetres may lead to a substantial change in vegetation and may strongly affect peat accumulation and mineralization rates and associated functions.
If the peatland is only recently drained, and peatland soil hydraulics and relief have not yet been affected, restoration measures can be restricted to making the drainage structures

ineffective, e.g. by damming, filling-in ditches or by destroying subsurface drainage pipes. Additionally measures for re-establishing flora and fauna may have to be taken.

Most peatlands are, next to rainwater, dependent on surface- or groundwater. Therefore, a peatland can also be affected by hydrologic interventions outside the area itself that impact on water levels, dynamics or quality in the mire. The latter is obvious in case of pollution or eutrophication of incoming surface water. Less obvious, but often equally important, is decreased groundwater inflow into the mire as a result of drainage or water extraction in the hydrological catchment of the mire, even on kilometres distance. This may lead to increasing rainwater influence, acidification, eutrophication (because hitherto unavailable phosphates become mobilised), vegetation changes, and a loss of rare species, even though the water *levels* are hardly affected. Especially oligo- to mesotrophic, subneutral to calcareous mires have become rare in this way.

If such changes in the hydrological landscape setting have taken place, restoration must involve hydrological interventions in the larger surroundings or significant hydrochemical engineering on-site.

Changes in the peatland's hydrology lead to changes in ***soil hydraulic conditions*** – certainly on the longer run. Processes induced by drainage include:

- subsidence, i.e. the lowering of the surface,
- compaction,
- fissuring through continuous shrinkage and swelling, particularly in drier climates, and
- decomposition and mineralization (conversion of organic material to inorganic substances).

These processes change the hydraulic peat properties (porosity, storage coefficient, hydraulic conductivity, capillarity) and these changes are largely irreversibly. They may decrease the peatland's capacities for water storage and regulation. The formation of vertical and horizontal fissures impedes upward (capillary) water flow and lead to a more frequent and deeper drying out of the soil. Through increased activity of soil organisms drained peat soils become loosened and fine-grained and may eventually become unrewettable.

Restoring peat hydraulic conditions is virtually impossible. The compacted peat prevents the water from entering the peat body, the decreased storage coefficient of the peat leads to larger water level fluctuations, which increases peat decomposition (Fig. 12). This means that peatlands where the hydraulic peat properties have been changed often cannot be restored to their former hydrological functioning, but that *alternative restoration aims* have to be formulated.

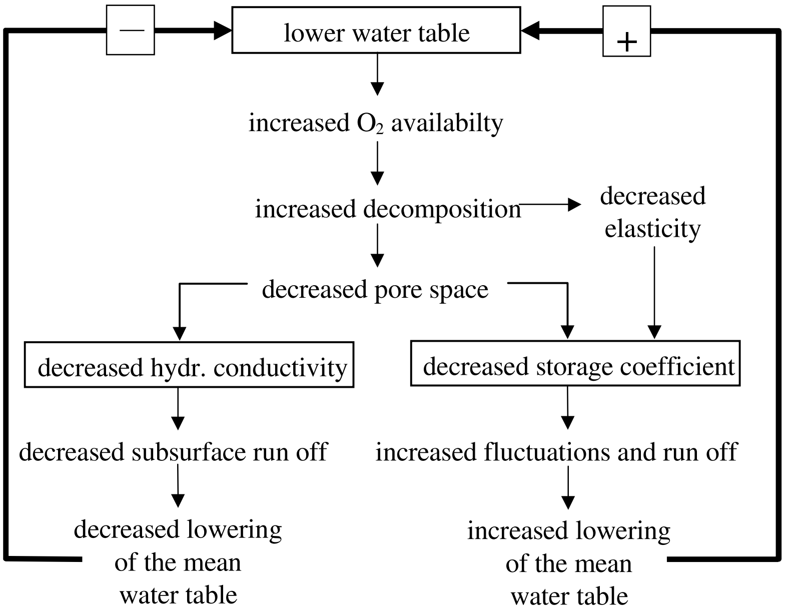


Fig. 12: Feedback mechanisms between lower water levels and hydraulic peat properties

Percolation mires, for example, originally kept their stable water level by a large water supply that could easily be distributed by percolation through the permeable peat. In degraded state, the compacted peat cannot conduct water anymore and water has to be distributed via surface flow. Acrotelm mires normally keep their water levels stable by the large storage capacity of their peats. In degraded state, the compacted peat cannot provide this function anymore and the water, necessary for maintaining high and stable water levels for renewed peat formation, has to be stored above the peat.

As undrained peat consists of 85 – 95 % of water, peatland drainage inevitably leads to substantial changes in the ***peat relief*** (of up to several meters!). In natural mires, a strict relationship exists between the form (surface relief) of the peatland, the hydraulic conductivity of the peat, and the amount of water that is transported through the peat body. A change in relief, through drainage, peat extraction, fire or whatever reasons, changes this delicate balance and the results cannot easily be predicted because a whole chain-reaction of processes with opposing effects are triggered:

- The change in relief leads to a change in water outflow from the peat and to an increased surface run-off, which leads to a drop in water level (which again changes the relief and may increase the amount of water transported via the peat).
- The lower water level causes compaction and increased decomposition of the peat, which may lead to a lower hydraulic conductivity (smaller pores) but in case of cracking of the peat also to increased drainage.
- The lower water levels and larger water level fluctuations encourage the establishment of higher (trees, shrubs) and deeper rooting (dwarf shrubs, grasses) vegetation, which affects the hydraulic peat properties through mechanical cracking (wind!) and perforation. The taller vegetation may furthermore enhance evapotranspiration leading to lower water levels etc...

The hydrological imbalance resulting from the changed peatland form is often addressed by remodelling the peatland relief to the groundwater surface of the degraded peatland. In case of bogs, the expectation that this results in an overall groundwater level at the peatland surface mostly doesn’t come true. The compact peat at the surface (strongly humified Sphagnum peat) mostly has a small storage coefficient that inevitable water losses through evapotranspiration continue to lead to significant falls of water levels in summer.

3.2.2 Legal constraints

Restoration planning has to consider legal constraints. Special permission might be required from:

- international law relevant to peatland restoration (Table 7),
- mining legislation, e.g. for the extraction of peat to dam and fill drains or to shape an optimal relief,
- construction legislation, e.g. for constructing buildings (shelters for guards or visitors, viewing platforms), water regulation devices (weirs, dams) and access facilities (paths, boardwalks, bridges, roads),
- water legislation, e.g. for changing drainage patterns and water levels by blocking ditches, impounding streams, groundwater extraction, discharge or supply of water, creating water reservoirs or lakes,
- waste disposal legislation, e.g. for importing foreign filling or construction materials into the site.

Possible rights (common land, rights of way, turbary, riparian, mineral, shooting and grazing rights) as well as the location of public facilities (gas pipes, electricity lines, and roads) have to be taken into consideration in any restoration project.

Table 7: International conventions and agreements relevant to mires and peatlands (see also Gardner 2003)

United Nations Framework Convention on Climate Change	http://www.unfccc.de/
Convention to Combat Desertification (UNFCCD)	http://www.unccd.int/main.php
Convention on Wetlands of International Importance Especially as Waterfowl Habitat (RAMSAR)	http://www.ramsar.org/
Protocol to Amend the Convention on Wetlands of International Importance Especially as Waterfowl Habitat	http://ramsar.org/
Basel Convention on Transboundary Movements of Hazardous Wastes and their Disposal	http://www.basel.int/
Bonn Convention on Migratory Species (CMS)	http://www.wcmc.org.uk/cms/
Convention on Biological Diversity (CBD)	http://www.biodiv.org/
Convention on International Trade in Endangered Species (CITES)	http://www.cites.org/
Vienna Convention for the Protection of the Ozone Layer	http://www.unep.ch/ozone
Montreal Protocol on Substances that Deplete the Ozone Layer	http://www.unep.org/ozone/
Lusaka Agreement on Cooperative Enforcement Operation Directed at Legal Trade in Wild Fauna and Flora	
Regional Seas Conventions	http://www.unep.ch/seas/
Barcelona Convention (Mediterranean Action Plan)	
Convention on Trade in Dangerous Chemicals and Pesticides (PIC)	http://irptc.unep.ch/pic/
Convention on Persistent Organic Pollutants (POPs)	http://www.chem.unep.ch/pops
Aarhus Convention on Access to Information, Public Participation in Decision Making and Access to Justice in Environmental Matters	http://www.unece.org/env/pp/

In many countries there is a statutorily ruled commitment for the analysis's of possible effects of planned activities onto the environment (*Environmental Impact Assessments,* EIAs). Information's on Environmental Impact Assessments can be found under:

http://ec.europa.eu/environment/eia/home.htm and
http://www.sciencedirect.com/science/journal/01959255.

Activities that oblige an EIA are indicated in the EIA laws, which also determine, who has to conduct the study, when it has to be conducted, within what period of time, and which aspects have to be given special attention to. The set-up of an EIA, the draft and final reports may be discussed in public before final decisions are made.

As obtaining all necessary licenses might be time consuming, it might be useful to undertake the project in stages.

3.3 Public participation and stakeholder involvement

The success of a planned restoration project will depend on public support and acceptance. In a democratic society individuals have the right to be informed or consulted about matters that might affects them. A clear understanding of the project background and goal provided to authorities, stakeholders, and the general public (Fig. 13) will involve as many people as possible in the planning of the project from an early stage on. In Europe the Aarhus Convention (www.unece.org/env/europe/ppconven.htm) requires that there is opportunity for public participation in decisions about developments that may have a significant effect on the environment. Article 6(4) of the Aarhus Convention states that: "each party shall provide for early public participation, when all the options are open and effective public participation can take place".

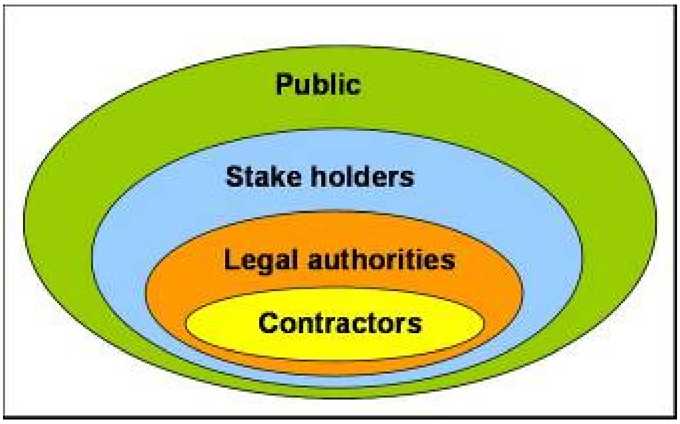


Fig. 13: Target audience during the preparation of restoration projects

Public participation is a key factor for the success of every restoration project as it supports the legitimacy of decision-making and the enhancement of democracy. Its "bottom-up" approach allows individuals or groups with a weak voice to exert influence on decision making. Public participation also enriches the planning phase by sharing knowledge and resources as it raises awareness and responsibility, increases transparency, resolves conflicting views and identifies realistic goals, determines needs and desires, and enables social learning (Petts & Leach 2000).

Public participation means to ask and encourage the public to directly and actively take part in the process of decision making. According to the power that is given to the public, there are different degrees of *participation*. The lowest degree of participation means that the responsible authority only provides *information* about previously made decisions. In other cases it provides information's to certain topics to collect the public's *feedback*, which will be taken into its consideration. The public can also be directly involved into decision making e.g. by *consultation*. The highest degree of participation means that a determined group of individuals is enabled to *decide* on its behalf about certain questions.

If contrasting aims are appearing, a well organised form of public participation may lead to a decision more or less satisfactory for every party involved. There are numerous participative consultation methods (Rowe & Frewer 2006) that are appropriate to provide attendance for a great number of people (chapter 3.3.1).

3.3.1 Methods for enhancing public participation

There are numerous methods to enable public participation in environmental decision making (Vancouver Citizens Committee 2006, OECD 2001), including:

- Education and provision of information,
- Information feedback,
- Involvement and consultation,
- Extended involvement.

Education and provision of information

Leaflets and brochures include written material that is used to spread information, to change people's views and to increase transparency. This material can be used to reach a wide audience, but is also useful to reach particular target groups.

Newsletters are a flexible tool of publicity that can be designed to changing / different needs of different audiences. Newsletters are useful to convey information that may involve a series of publications.

Unstaffed exhibits or displays may include graphic presentations to visualize proposals. If they are placed in public areas the audience may assimilate the information at a suitable time.

Advertisements may be used to spread limited information (e.g. announce proposals, arrangements for meetings and other activities). If they are adequately spread they can reach a large audience. Otherwise only those are reached that read the publication, where the advertisement is placed.

Articles in public newspapers and *radio or television* comments are a cheap way of spreading information's for a local audience. The contributions have to be prepared carefully, because limited editorial control may lead to problems of interpretation.

Videos and DVDs are an increasingly cheap, professional and credible way to spread propaganda. The audience may consume the information that may contain graphics or other images at their convenience.

Organised site visits are a classical tool to bring issues to life by providing experiences of particular activities and issues at case study sites.

Information feedback

If *staff* is available *at* public *exhibitions or displays* questions can be responded and comments may be received.

Staffed telephone lines can be provided for interested people to obtain information, to ask questions and to make comments about proposals. Because it is not intimidating this method is a convenient way to receive comments from interested parties.

Regularly updated *websites* are a cheap way of providing information but also of inviting global readers for feedback. As not all interested parties might have internet access other means of participation have to be provided.

A limited number of participants may be included into *telephone conferences*. As this requires technical possibilities and staff that is able to operate it, this method may be expensive, but it enables people with difficulties to travel to talk to officials or politicians and to take part into the discussion.

A *public meeting* is a possibility to gather stakeholders and affected parties to present and exchange information and to discuss proposals. Such meetings should be carefully prepared. They are very complex and unpredictable and might be hijacked by certain groups. The following aspects should be taken into account when organizing a public meeting:

- Set clear objectives for participation.
- Identify and target all the relevant stakeholders.
- Adapt the participation process to the objectives and needs of all stakeholders.
- Ensure sufficient time for participation.
- Make essential information available in advance, to enable participants to identify questions.
- Provide adequate opportunities for all participants to name issues for discussion, e.g. by employing an independent and well prepared chairman or facilitator.
- Realize an honest and understandable procedure, e.g. by offering opportunities for the interviewing of experts.
- Guarantee a credible and interactive process of participation that generates responses, e.g. by stimulating group discussions amongst the participants themselves.
- Provide a clear understanding of the situation, its challenges and possible solutions, e.g. by presenting background knowledge about different ideas and concerns.
- Set out clear evidence of how participants' views have been considered in the final decision (Petts & Leach 2000).

To gather information from people that would not go to public meetings, *surveys, interviews and questionnaires* (self administered, face to face or via telephone) are often used. It might be very expensive to design a proper survey, but poorly prepared surveys often have a low response rate.

Involvement and consultation

A limited number of participants can exchange information and discuss proposals at *workshops*. Workshops can be targeted at certain stakeholder groups to solve particular problems. They are more effective if the number of the participants is kept small.

Forums can be organised to gauge response to planned actions and to gain understanding of the perspectives, ideas and concerns of invited participants. This is an intensive way of exchanging and might be expensive because facilitating and serving is required. Because only a small number of people is able to participate additional possibilities for participation are necessary.

Open house means that interested parties are invited to visit a certain location (e.g. site or operational building or office) on their convenient time to view information materials and to ask questions about proposals.

The same may be organised for a potentially global audience by *"open houses" on the internet* (e.g. bulletin boards, mailing lists or discussion forums). This is a cheap way of including people that have access to the internet.

Extended involvement

Community advisory committees are small groups of people that are representing certain interests or areas of expertise. Such committees can discuss parts of the proposal in detail.

Planning for real is a process of community consultation that begins with contacting local networks to identify problems, to generate ideas and to focus on local priorities by establishing local working groups that may participate during the project planning.

Citizens' Juries (a microcosm of the public) enable a representative group of jurors to participate in the planning of proposals. Jurors consider an issue over three or four days, ask questions, discuss the issue among them, and finally develop a concluding report.

It might be difficult to realize a broad public participation in areas with little tradition or with ethnic minorities. In such cases participation may be promoted by:

- meeting people at regularly visited places, rather than expecting them to come to a special venue,
- involving different communities representing organisations or individuals,
- distributing written materials in the local language(s),
- engaging interpreters for face-to-face interviews and translators for written responses,
- training staff in cultural awareness, anti-racism and equal opportunity issues,
- spread information by different media (e.g. via newspapers, television, radio, and internet),
- creating an atmosphere of community events (guided field trips, action days, exhibitions, and presentations),
- offering refreshments, or tea and biscuits, providing encouragements (e.g. prizes or gifts).

3.4 Planning the measures

During the next step, appropriate instruments or measures to reach the aim have to be determined by careful analysis. When restoration turns out to be technically possible, other questions become opportune, including:
What will be the effects of the actions undertaken? What are possible side-effects during the restoration process and when the aims have been reached? What are the effects outside of the area directly involved? What are the effects on the long run? (Environmental Impact Assessment, EIA).
How will the costs relate to the benefits? (Cost-benefit-analysis). Many factors may determine the eventual costs of a restoration project including:

- the costs for land purchase (of the site or of affected surrounding land),
- the costs of experts to study and interpret stratigraphical, hydrological, and biological site characteristics (an often underestimated post, that may be more cost intensive than the ultimate measures),
- the rents of machinery, equipment and operators,
- the costs of construction materials and their transport,
- the costs of plant material (incl. the growing of not available species),
- the wages of working staff,
- the costs for executive staff,
- the costs of compensation for disadvantaged stakeholders,
- the costs of regulating public access by the installation of boardwalks, signs and fences,
- the costs for monitoring and management.

To save costs, it is advisable to use - wherever possible - local materials (peat, wood, sods, sand). The use of foreign materials (impermeable cores of plastic or metal) may, however, be necessary to construct durable and optimally performing devices.

Restoration for nature conservation

Restoration for nature conservation is subject to extra boundary conditions, as in nature conservation the '*means*' are an implicit part of the '*ends*'.
'*Natural*' is everything that is originating or has originated spontaneously. In contrast, '*artificial*' is every deliberate (conscious) act and its result. Every deliberate act therefore increases the artificiality and decreases the naturalness of a restoration project.
For nature conservation it is therefore imperative to limit activities to the minimum: *"Doing less is better than doing more."*
The artificiality of measures increases in the following order:

1. "*doing nothing*": the passive, defensive measures necessary to prevent injury to existing values (= external management, veto-regulation), e.g. refrain from cleaning ditches to support sukksession; prohibition of digging drainage ditches in a mire;
2. "*consciously doing once*": one-off activities to improve conditions, e.g. the blocking of drainage ditches in a peatland to stop drainage;
3. "*consciously doing continually*": the active, continual measures necessary to maintain favourable conditions (= internal management, prescriptive regulation), e.g. annual mowing and removal of vegetation to support less competitive plant species.

Next to the choice of appropriate materials, strategic management planning also includes
- the choice of skilled contractors (preferably with ample peatland experience, because peat is a very special and sometimes risky construction material and substrate),
- the choice of the suitable time of the year (as peatlands are in some seasons better accessible and processible than in others),
- the planning of the available money, taking possible extreme weather conditions into account,
- the implementation of adequate safety regulations adapted to the specific peatland conditions.

3.5 Monitoring

Monitoring, i.e. closely and systematically observing, enables to notice significant changes and is therefore of high value to answer the following questions:
- Have objectives been met or surpassed?
- Was the money spent effectively and efficiently?
- What can or could have been improved?
- How can the management be adapted best?

Making this information available allows the improvement of other projects and sets a foundation for future monitoring programmes.

Monitoring objects, methods, and periods have to be adapted to the individual characteristics and peculiarities of each project (Table 8).

Table 8: Aspects to consider when designing a monitoring scheme

Site history	What is the actual level of degradation (see chapter 2.1)?
	Did the site support the target habitat in recent years?
	Did the site contain target species (condition of the seed bank)?
Site location	Where are the sources for spontaneous recolonisation (target species)?
	Where are disturbances (human activities, waste, pollutants, and problem species)?
	How does the site interfere with its surrounding?
Site situation	Depending on size, zonation and complexity of the site an adequate number of monitoring areas have to be established (e.g. sloping sites will show different development in the upper than in the lower parts).
Applied methods	Will natural revegetation take place or was initial support of the establishment applied?
	Where there changes in the site's hydrology?
	Are there management or maintenance requirements (e.g. to maintain a certain water level by pumping of water or by adjusting weirs)?
Project aims	What is the project focusing on?
	What is the appropriate scale of monitoring (the whole catchment; focal areas of the site) and where should sampling plots be located (along transects, as nested plots, in regular or stochastic design)?
	How long and how intensive should the monitoring take place (e.g. to assess fluctuations during an adequate period)?
	Is it possible to optimise the monitoring by modelling selected parameters?

As with restoration aims, monitoring objectives should be simple, measurable, achievable and repeatable. To monitor changes in relation to the applied measure the starting situation should be assessed and documented.

Successful monitoring requires the appropriate time of the year (considering the sites accessibility, flowering, mating or breeding periods of target species) and the right monitoring strategy. Depending on the question and the available budget different monitoring strategies (evaluation or sampling) are conceivable.

Evaluation

The recorder assesses the condition of the whole site by valuing the condition of selected site parameters. The results are recorded during the walk. In most cases a w-walk (Fig. 14) is a useful way to cover all representative sections of a site. For more difficult shaped sites provisional planning (e.g. with the help of aerial photographs or large scale maps) will be necessary to plan the monitoring walk.

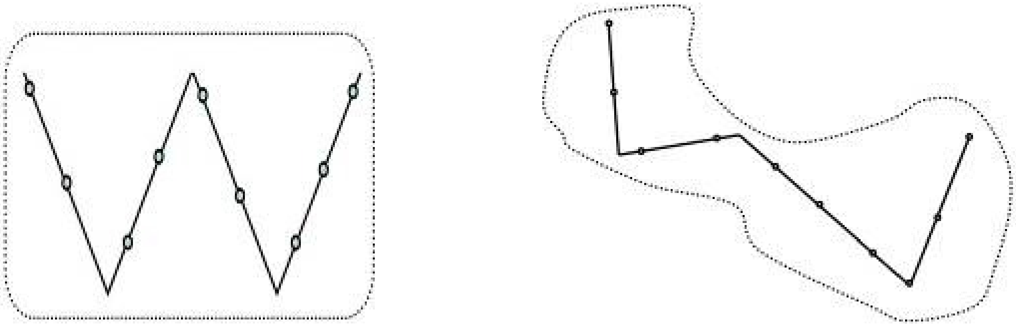


Fig. 14: W-walk as appropriate method for evaluating or sampling field recordings.

Under uncomplicated conditions (e.g. even and homogenous fen meadows) the evaluation of easily assessable attributes (e.g. vegetation mosaic, surface erosion or over grazing) is recommended rather than the laborious sampling of detailed site parameters that can not be recognized from a distance (e.g. hydrological and chemical peat properties, presence or abundance of target species). Before monitoring, focal interests and appropriate indicators should be identified.

Plant and animal (indicator) species may indicate the existence of wanted or unwanted environmental conditions by their absence or presence.

Ecological site characteristics (e.g. the cover of trees, shrubs, grasses and mosses as well as the area of bare peat and litter) may indicate complex changes on site.

Land use characteristics (e.g. new buildings, roads, paths; agricultural or forestal land use practises on site or within the catchment) may indicate relevant changes.

Sampling

Sampling involves the quantitative assessment of site parameters at selected and marked sampling positions (permanent plots). Their number has to be modified in relation to site size and number of relevant complexes (e.g. open or afforested areas, open water bodies, bare peat surfaces and streams).

Documentation

A well prepared recording sheet which is drawing attention towards the previously selected indicators helps to standardise the recordings of every field visit. Examples for the design of recording sheets are given by Mitchley et al. (2000), Quinty & Rochefort (2003), Brooks & Stoneman (1997a), Wagner & Wagner (2003), BUWAL & WSL (2002), BUWAL (2002a, b) BUW and Clarkson et al. (2004).

It is useful to take photographs (if possible from fixed points) at every field visit to provide visual histories of changes and to support monitoring of only rarely visited sites and sites for which monitoring resources are limited. Fixed photograph points can be marked by permanent electronic markers (e.g. magnets placed beneath the surface) or wooden or metal posts (both susceptible to vandalism). In every case it is useful to reference permanent structures on and off site (by direction and distance).

Especially when wide and monotonous areas have to be monitored aerial photography or remote sensing is very useful (see Jackson et al. 1995, Bindlish et al. 2006, Poulin et al. 2002). On a smaller scale positive results can be achieved by installing camera platforms or by using model aircrafts or balloons (Brooks & Stoneman 1997a).

All recording sheets and photographs (raw data) should be filed to prevent misleading interpretation.

For the monitoring of peatland restoration achievements a combination of the following components is recommended:

- Biodiversity: plant and animal species,
- Habitat diversity: distribution of surfaces and structures,
- Hydrology: water level and flow pattern, and
- Chemistry: availability of nutrients or poisonous substances.

3.5.1 Monitoring biological and habitat diversity

Field mapping, aerial photographs and satellite imagery are useful to monitor the distribution of habitat structures (microhabitats like open water bodies, mosaics of dry and wet spots, areas of bare peat). Additional data on the temporal variability of water levels, trophic status and disturbance (e.g. by herbivores, tourists, land use activities) are necessary for assessing habitat quality (Davidsson et al. 2000). Information about vegetation structure (height, presence of different layers, spatial distribution of vegetation types) should be assessed during field visits (Atkinson 1985 in Clarkson et al. 2004).

To produce comparable data on biodiversity, plot size and location have to be standardized and the taxonomic level of inventory has to be fixed. As it (due to limited recourses or taxonomic complexity) generally will not be possible to assess all species, focal groups (*target species*) have to be selected and monitored with a carefully designed methodology.

Target species

In degraded peatlands the original communities are often no longer present. Therefore the concept of *target species* for restoration and monitoring was developed. These target species include *flagship species* (popular 'interesting' and 'nice' species like birds, orchids and butterflies) as well as *protected*, *rare* and *endangered species* (of national or international importance). But also *indicator species* that reflect important site parameters and *keystone species*, which play a special role as ecosystem 'engineers', are useful targets of monitoring.

For practical reasons monitoring should as far as possible concentrate on species that are easily recognizable and easy to register.

Bioindication

Plant and animal species are valuable indicators of complex environmental conditions. Especially plant species (that are bound to their habitat) reflect habitat changes in a detailed way by their presence, disappearance or absence. Important regional overviews for the indicator value of plant species are provided by Koska et al. (2001), Koska (2001), Ellenberg et al. (1991a, b) and Tiner (1991, 1999). Also the monitoring of selected animal species (e.g. dragonflies, butterflies, and amphibians) may deliver insight into complex habitat conditions. Monitoring strategies are described by Brooks & Stoneman (1997a), Eades et al. (2003), Budd (1991), Clarkson et al. (2004), Dryden (1997) and Treweek et al. (1997).
Vives (1996) and Crofts & Jefferson (1999) offer an extensive *monitoring* bibliography.

3.5.2 Monitoring hydrology and chemistry

The assessment of basic hydrological parameters is an essential part of peatland monitoring. Water levels and water level fluctuations play a major role in mire ecosystems (see chapter 1). Too high water levels may reduce plant productivity which negatively impacts on peat formation (Joosten 1993, Couwenberg & Joosten 1999). Too low water levels may encourage plant productivity, but also impede peat accumulation by enhancing aerobic decay (Clymo 1984).
The phreatic water level (the distance between groundwater table and the peatland's surface) may be measured in dip wells (countersunk, perforated PVC pipes, cf. Brooks & Stoneman 1997a, Bragg et al. 1994). Measurements of water level changes should be carried out regularly to assess their whole spectrum (e.g. due to weather changes, either with data loggers or at least once every week or fortnight).
To detect hydrological interrelationships between the peatland and its surroundings information on various hydrological processes have to be gathered (Fig. 15).

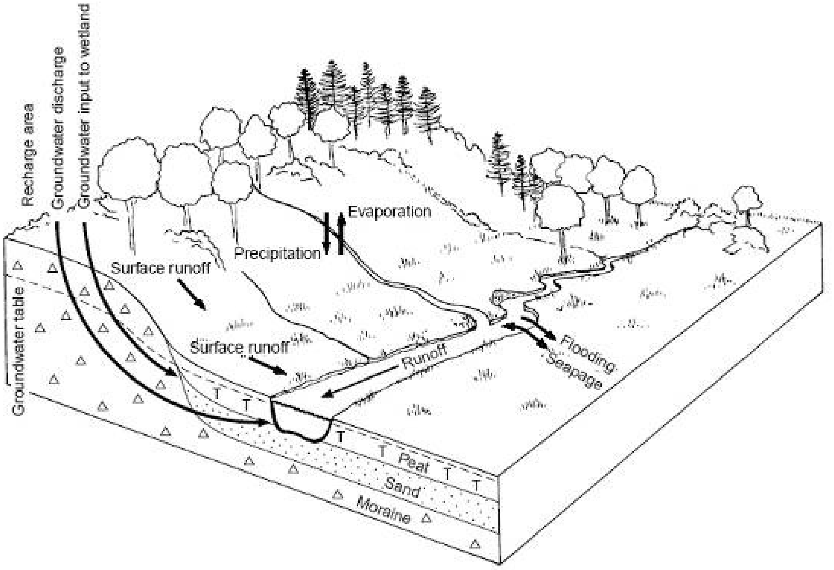


Fig. 15: Hydrological processes in a fen and its catchment (from Davidsson et al. 2000)

Geological maps, satellite or aerial images may offer useful information. Water flow dynamics (e.g. groundwater flow patterns) within the peatland depend on both the hydraulic conductivity as well as on hydraulic heads of different peat layers (Fig. 16).

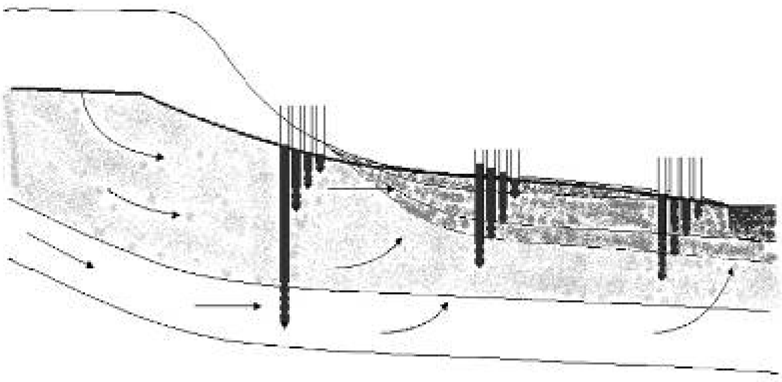


Fig. 16: Piezometer nests along a transect (from Davidsson et al. 2000)

The *hydraulic conductivity* or *transmissivity* is mainly determined by pore size, but also by pore shape and the connection between the pores and is a function of peat type, peat texture, and degree of peat decomposition (Ivanov 1981, Boelter 1965, Rizutti et al. 2004). Van der Schaaf (1999) describes different (field) piezometer-methods (e.g. rising or falling head method, pit bailing method) to measure and calculate hydraulic conductivities.

The *hydraulic head* (the distance between the potential water table (piezometric water level) in a certain depth and the peatlands surface) can be measured by piezometers (PVC pipes with a perforated filter in a defined depth, cf. Van der Schaaf 1999, Davidsson et al. 2000). This method enables to assess different water heads in different depths and with that the direction of groundwater movement. A higher hydraulic head in higher peat levels indicates water infiltration whereas a higher hydraulic head in the deeper peat layers points at an upward movement of water.

The trapping and transformation of nutrients and pollutants are common aims of peatland restoration (Trepel et al. 2000). To evaluate the success of the restoration in this respect, mass balances have to be calculated. This may be achieved by determining the difference in concentration and volume of the water flowing in and out the peatland (cf. Davidsson et al. 2000).

In case of low hydraulic conductivity of the peat (highly decomposed and compressed) and the underlying or surrounding mineral soil (e.g. clay), groundwater inflow or outflow is probably insignificant and can be neglected. Sandy soils, however, are more permeable and water contribution from and to the groundwater should be monitored. The collection of water for analysis can be done in groundwater tubes (e.g. piezometers) that are brought down to the depth in question. In peatlands with surface flow, water should be sampled from all relevant in- and outlets (incl. precipitation, measured by rain gauges).
In every case a comprehensive sampling plan should be designed to cover all significant in- and outflows at relevant times (e.g. the major part of the annual transport of material might happen after precipitation events).

Further reading: Chason & Siegel (1986), Devito et al. (1997), Dietrich et al. (2001b), Eades et al. (2003), Edom (2001), Edom et al. (2007), Fraser et al. (2001), Grootjans et al. (2006), Hayward & Clymo (1982), Hemond & Goldman (1985), Ingram et al. (1974, 1985), Ingram

(1983, 1992), Price et al. (2003), Reeve et al. (2000), Romanov (1968), Rycroft et al. (1975), Scottish Wildlife Trust & English Nature (1995), Trepel et al. (1999), Trepel & Kluge (2003), Wheeler & Shaw (1995b) and Zinke & Edom (2006).

Packing list for monitoring field trip

- Recording sheets and inkstand
- Permanent markers
- Topographic map
- Aerial photographs (at suitable scale, preferably colour)
- GPS or compass
- Tape measure to delineate boundaries
- Poles to mark permanent plots (4 per plot)
- Magnets for marking permanent plots
- Camera
- Folding rule to measure vegetation height
- Literature for determining species
- Handlense
- Paper bags for plant sampling
- Knife for plant and soil sampling
- Plastic bags for soil sampling
- Field pH meter
- Field conductivity meter
- Weatherproof clothes (rubber boots)

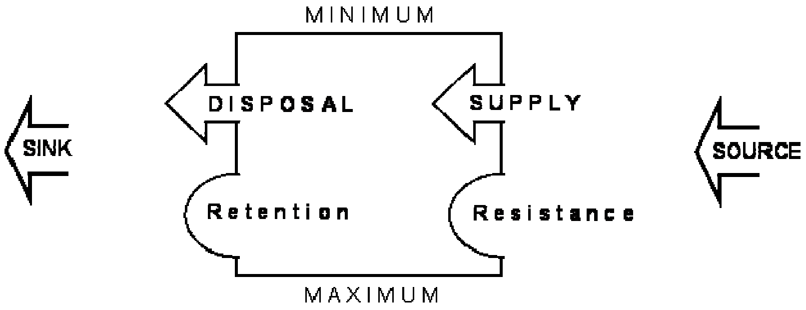
Checklist for restoration projects:

1. Define the problem and acquire general understanding.
2. Collect sufficient baseline data to identify problems and to estimate success chances.
3. Use the support of qualified technical experts, agencies, and organizations for planning
4. Identify goals and objectives.
5. Focus on the restoration of a possibly self-sustaining ecosystem.
6. Clarify budget issues.
7. Clarify legal requirements on local, regional, national and international level.
8. Identify and engage private or official stake holders.
9. Enable public participation.
10. Consider possible risks and uncertainties.
11. Establish consensus about the projects mission.
12. Identify measurable indicators to verify the project performance.
13. Design monitoring and management plans.
14. Test critical procedures in small scale experiments to minimize risks of failure.
15. Realize the operational availability of the site.
16. Organize trained supervision of work.
17. Employ well trained operator and workers.
18. Implement restoration measures.
19. Follow safety regulations.
20. Stick to time scale.
21. Check if expected objectives can be achieved.
22. Correct emerging problems.
23. Modify unattainable objectives
24. Document intermediate project stages.
25. Check adequacy of the monitoring program.
26. Investigate the extent to which project goals and objectives are achieved.
27. Consider if critical peatland components and functions have been restored.
28. Analyse ecological, economic, and social benefits realized by the project.
29. Identify future management and maintenance requirements.
30. Organise management and maintenance.
31. Share learned lessons with interested parties on:
    - duration of each project phase and the total project,
    - costs and cost-effectiveness of each project phase,
    - total costs of the project.

4 Standard management approaches

Peatlands are complex systems because they
- consist of sophisticated interrelations of vegetation, water and peat,
- provide a wide variety of products and services, and
- can be damaged by a large variety of actions.

Experience has shown that peatland restoration projects that depart from too simplistic approach often fail. A useful instrument to identify necessary restoration steps is the ecosystem model of Van Wirdum:



It illustrates that all relations of ecosystems and their surroundings that can be brought down to
1. **input**-relations, when the system itself acts as a **sink** (for another source)
2. **output**-relations, when the system itself acts as a **source** (for another sink),
and are ruled by two limits of tolerance:
A. the limit of **minimally required**
B. the limit of **maximally tolerable**.

A peatland may thus suffer from four fundamentally different types of degradation:
1.A. **Underfeeding**: The system has too little input of something.
2.A. **Stoppage** (constipation, blocking): The system has too little output of something.
1.B. **Overfeeding** (pollution, poisoning): The system has too much input of something.
2.B. **Loss** (deprivation): The system has too much output of something.

Against these four types of degradation, four types of restoration measures have to be applied:
I. **Supply**: measures against underfeeding (“getting in”).
II. **Disposal**: measures against stoppage (“getting out”).
III. **Resistance**: measures against overfeeding (“keeping out”).
IV. **Retention**: measures against loss (“keeping in”).
Resistance and retention are defensive measures: they fail when the maximally allowed levels are exceeded. Supply and disposal are offensive measures: they fail when the minimally required levels are not reached.

In this chapter we use these basic types of measures to organize the multitude of measures in restoration practice. We elaborate these relations for the different landscape components with respect to the three major aims of peatland restoration:
- the restoration of peatland biodiversity,
- the restoration of peatland hydrological functions, and
- the reduction of greenhouse gas emissions from peatlands.

4.1 The restoration of peatland biodiversity

Degradation usually affects the typical biodiversity of peatlands. Peat extraction, fire or erosion may even lead to bare peat surfaces. When left on their own, such areas (eventually) re-vegetate (from the seed bank and incoming diaspores), but often the focal mire species do not re-establish. They require the restoration/regeneration of adequate habitat conditions by removing the negative impact of humans, animals (e.g. overgrazing), noxious substances, fire and erosion (Table 9).

Table 9: Measures to restore biodiversity in peatlands

	What	Why	How
Keep in	**Species**	Support remaining populations or individuals of priority species by:	Improving habitat conditions Reducing human impact Reducing impacts of herbivores or predators
	Water	Prevent water losses from focal site to provide adequate water levels for focal species by:	Maintaining catchment water table Raising catchment water table Increasing water level on site Decreasing evapotranspiration
	Peat	Maintain remaining peat as habitat and substrate of focal species by:	Keeping up permafrost Reducing aerobic decomposition Reducing erosion
	Management	Support remaining populations or individuals of priority species by:	Continuing traditional management
Keep out	**Damage**	Reduce damaging impacts of humans and animals to focal species by:	Reducing human impact Reducing impacts of animals
	Water	Prevent too high water levels (harmful to focal species) by:	Reducing water surplus
	Noxious substances	Reduce input of unwanted substances (incl. sediments) that may harm focal species by:	Providing water of desired quality Reducing erosion
	Fire	Prevent damage to focal species and peat losses due to fire by:	Preventing (expansion of) fire
Get in	**Species**	Introduce individuals of focal species (incl. nursing species) by:	Introducing focal species
		Encourage reproduction of focal species by:	Improving habitat conditions Suppressing unwanted species
	Water	Bring in enough water to provide adequate water levels to support focal species by:	Raising catchment water table Increasing water level on site
		Supply water of desired quality to re-establish and support focal species by:	Providing water of desired quality Raising catchment water table
	Peat	Re-establish peat accumulating species by:	Improving habitat conditions Introducing keystone species
Get out	**Biomass / litter**	Improve habitat conditions of focal species (creating germination niches) by:	Improving habitat conditions Reducing unwanted substances
	Species	Reduce non-focal species that cause harm to focal species by:	Suppressing non-focal species Improving habitat conditions
	Water	Draw off water surplus to establish adequate water levels for focal species by:	Reducing water surplus
	Noxious substances	Dispose noxious substances (poisons, nutrients) by:	Improving habitat conditions Reducing noxious substances

On the other hand, various semi-natural plant and animal communities depend on traditional human management that maintains favourable growing conditions by reducing or providing nutrients, by suppressing non-focal species, by rejuvenating focal species and by introducing fresh genetic material. If the re-establishment of traditional management (grazing, scything and burning) is impossible, modern techniques with similar effects (mowing, mulching) have to be installed

From the example of 'grazing' it becomes clear that the same activity can be both harmful and beneficial, depending on aims, circumstances, densities and frequencies. Therefore it is necessary to evaluate the effects of methods before they are established.

In the following we specify and explain the major measures listed under the *How*-column in Table 8. The measures refer to the reference list at the end of this chapter.

4.1.1 Improve habitat conditions by:

1. *Regulating nutrient availability*

a) Reduce nutrients by mowing and removing of biomass from the site. The action should take place during times of high production (before the starting of decay).
see: 1 - 12

b) Increase nutrient reduction by harvesting biomass of nutrient consuming species.
see: 1, 12

c) Reduce nutrients by preventing influx of eutrophic water.
see: 4, 9, 14, 16

d) Increase nutrient availability by spreading natural or artificial fertilisers.
see: 1, 9, 12, 15, 17 - 25

2. *Regulating base saturation*

a) Increase base saturation by spreading lime and preventing influx of acidic water.
see: 1, 3, 12, 20, 25

b) Reduce base saturation by preventing influx of geogenous (hard) water to increase influence of precipitation water.
see: 3, 26

3. *Creating niches*

a) Suppress non-focal species (e.g. fast growing, light consuming plants) by the use of selective herbicides (spraying, painting cut stumps) and pesticides (spraying, spooning baits), by mechanical damage (grazing, mowing, burning, pulling, ring barking, sawing or cutting down, knocking off, verticuting, drowning) and by reduction in numbers (supporting or introducing of predators, chasing, catching, trapping, hunting, poisoning).
see: 1, 5, 9, 11, 12, 14, 27 – 58, 131, 137

b) Create small pools (e.g. by digging, bunding or blasting holes) in the peat surface.
see: 3, 27, 28, 59 - 64

c) Stimulate settlement of focal species by putting up artificial nesting or breeding sites.
see: 3, 28, 30

d) Provide adequate shelter to focal species by establishing nursing species.
see: 12, 22, 24, 49, 53, 62, 63, 65 - 71

4. *Refreshing genetic material*

a) Allow natural migration of focal species (reaching and leaving the site) by establishing habitat connections and enriching ecological infrastructure (ditches, dry-stone walls, hedges, shrubs, grass strips, streams).
see: 31

b) Introduce fresh genetic material by introducing or exchanging individuals of focal species.
see: 31, 21, 24

5. *Reducing negative impacts caused by:*
- Humans (*see 4.1.3*)
- Animals (*see 4.1.4*)
- Unwanted substances (*see 4.3.5*)
- Fire (*see 4.3.7*)
- Erosion (*see 4.3.4*)

4.1.2 Introduce target species by:

1. *Supporting natural immigration*
Allow natural immigration of diaspores via wind and water by establishing habitat connections or habitat connecting processes (e.g. flooding).
see: 9, 72 - 77

2. *Connect habitats by grazing*
Enable diaspore transport via animals by grazing of species relevant habitats and the focal site at time of seed ripeness.
see: 138, 139

3. *Connect habitats by cultivating*
Enable diaspore transport via machines by cultivating (e.g. mowing) of species relevant habitats and the focal site at time of seed ripeness.
see: 12, 47

4. *Spreading mown material*
Introduce diaspores and plant fragments by spreading of mown material from focal species habitats (antropochorie). Mow at time of seed ripeness and prevent damage on receptor site by spreading material during appropriate periods (with dry or frozen ground). Spread mown material in adequate density and provide appropriate shelter (e.g. spread straw mulch on *Sphagnum* fragments).
see: 5, 9, 10, 12, 18, 19, 22, 36, 51, 62, 63, 66, 74, 78, 79, 137

5. *Spreading seeds*
Introduce previously collected seeds of focal species (e.g. by hydroseeding).
see: 1, 5, 10, 21, 22, 31, 36, 72, 74, 80, 131, 132

6. *Planting*
Plant pre-grown seedlings, saplings, shoots or adult plants in adequate density at adequate time.
see: 3, 5, 10, 20, 22, 24, 27, 61, 72, 81 – 83

7. *Transplanting sods*
Enable diaspore transport via soil by collecting sods from habitats of focal species and spread them in adequate density.
see: 10, 21, 22

4.1.3 Reduce human impact by:

1. *Providing access to less vulnerable areas during less vulnerable periods*
   a) Encourage access by offering attractions (paths, boardwalks, shelter, maps, signs, observation platforms, guided tours).
   see: 3, 27 – 30, 36, 84, 86, 121
   b) Encourage access by targeted education.
   see: 27, 29, 30, 84, 86

2. *Regulating access by zoning*
   see: 2, 3, 17, 87 - 89

3. *Reducing access to vulnerable areas during vulnerable periods*
   a) Prevent access by regulations (prohibits, signs, fines, guards) or obstructions (ditches, shrubs, fallen tress, swampy ground, wild animals, fences, gates).
   see: 17, 84, 86, 89 - 92
   b) Regulate access by targeted education.
   see: 81, 83, 86

4.1.4 Reduce impact of animals by:

1. *Providing access to less vulnerable areas*
   Draw attention to selected areas by establishing feeding and drinking places or shelter and hiding places.
   see: 28, 93

2. *Preventing access to vulnerable places*
   Impede access by establishing obstructions (ditches, swampy ground, fences, gates).
   see: 3, 17, 56, 93

3. *Reducing numbers*
   Reduce numbers of animals by hunting, chasing, trapping or poisoning.
   see: 12, 17, 43, 93

4.2 Restoration to improve peatland hydrology

The success of any restoration project depends on the durable re-instalment of appropriate site conditions. There is no universal strategy to restore drained peatlands as conditions differ widely depending on climate, water and peat chemistry as well as on topography. It is, however, possible to define general principles for the solution of similar problems. The main focus of restoration of hydrological conditions lies on rewetting, i.e. raising the level of permanent water saturation and reducing the amplitude of water level fluctuations by reducing water losses (incl. extraction, surface runoff, sub-surface seepage and evapotranspiration) from the site and from the adjoining catchment. The main challenge is to store enough water during periods of water surplus to prevent drought during periods of water shortage.

4.2.1 Elevate water level on site by:

1. *Managing existing drainage systems*

a) Reduce water losses by increasing water back up heights of sluices and weirs.
see: 27, 1, 28, 3, 61, 11, 55

b) Remove subsurface drainage pipes by excavation or destruction.
see: 1, 11, 55, 61, 94, 95

2. *Increasing natural rewetting*

a) Slow down water flow by introducing beavers into appropriate habitats.
see: 96, 97

b) Slow down water flow off by introducing trees, rocks and other natural obstructions into streams.
see: 3, 11, 61

3. *Damming of ditches*

Dams should be constructed of adequate materials (considering availability, costs, loading capacities, and life time). The use of natural materials (wooden trunks or planks, wood chips, peat and mineral soil) contributes to limiting costs for transport and purchase (and keeps the artificiality of the measure low). The use of artificial materials (concrete, plastic or metal sheets) may be required in selected cases.

In case of highly permeable peat, dams should be erected in trenches that reach into low permeable subsoil or less permeable peat layers.

Determine possible maximum loads of accumulating water (e.g. after heavy rain or snow melting events) and erect structures stable enough to prevent failure. Consider safety regulations, take professional advice for design, and ensure regular inspections and necessary management to prevent the collapsing of dam constructions.

Identify appropriate times to enable uncomplicated access and construction (e.g. during times of low water level or frost) to reduce damage to the site and costs of the project.

Implement phased inundations to enable initial establishment of vegetation.
see: 3, 10,11, 27, 29, 36, 40, 59, 61, 64, 84, 98 – 109, 134, 135, 136^

Table 10: Measures to restore peatland hydrological functions

	What	Why	How
Keep in	**Species**	Promote focal species (e.g. Sphagnum to restore acrotelm) by:	Improving habitat conditions
			Suppressing non-focal species
	Water	Prevent water losses to guarantee stable base flow into downstream ecosystems by:	Reducing evapotranspiration
			Increasing water level on site
	Water	Prevent water losses to limit water pollution (due to mineralization) by:	Reducing evapotranspiration
			Reducing water surplus
	Peat	Reduce peat mineralization to guarantee stable base flow of desired quality by:	Increasing water level on site
			Reducing evapotranspiration
			Raising catchment water table
			Reducing erosion
Keep out	**Damage**	Reduce peat compression or destruction of vegetation cover by:	Reducing human impact
			Reducing impacts of herbivores or predators
	Water	Reduce input of too much water to enable peat formation by:	Providing water of desired quality
	Water	Reduce input of unwanted water to restore desired water conditions by:	Increasing water level on site
	Peat extraction	Restrict peat extraction by:	Legislation and licensing
	Fire	Prevent peat losses (due to fire) that affect the peatlands hydrology by:	Preventing (expansion of) fire
	Noxious substances	Reduce input of substances (lime and nutrients that support peat mineralization, sediments and poisons that negatively affect water quality) by:	Providing water of desired quality
Get in	**Species**	Establish peat forming vegetation to restore the site's water filtering capacity by:	Introducing focal species
			Improving habitat conditions
	Water	Increase water supply to limit water pollution (due to peat mineralization) by:	Raising catchment water table
	Water	Increase input of water to restore desired hydrological conditions by:	Providing water of desired quality
			Increasing water level on site
	Peat	Restore peat formation to enable sequestration of nutrients and other unwanted substances by:	Introducing focal species
			Improving habitat conditions
Get out	**Noxious substances**	Reduce unwanted substances to guarantee desired water quality by:	Reducing unwanted substances
	Water	Draw off water surplus to enable peat formation by:	Reducing water surplus

4. *Complete infilling of ditches*
   Reduce water losses by complete infilling of ditches. Highly decomposed peat may be used because of its sealing properties and because it supports further stabilisation through vegetation. This is a cost effective measure as the material can be collected from the site. The extraction of peat may require permission from (national) mining legislation. Consider appropriate areas for peat extraction to keep additional damage low.
   If adequate amounts or qualities of peat are not available, other materials may be used. The use of woodchips that emerge from tree or brush cutting activities has shown positive results. It facilitates waste disposal but requires adequate compression.
   see: 11, 27, 55, 61, 106, 107, 110, 111, 134

5. *Bund walling*
   Reduce water losses and increase water storage by sealing marginal areas with bunds, made of low permeable peat or other water impermeable materials like clay or plastic.
   Because "bunding" raises the water level above its previous position; it has to be carefully planned, well done and regularly maintained.
   Professional advice for design and construction is required. This is cost intensive but necessary to come up to safety requirements.
   Water discharge appliances have to be integrated to enable outflow of water during and after periods of high rainfall.
   Paddy field-like cascades of bunds are necessary for rewetting sloping peatlands.
   Realise phased inundations to enable initial establishment of vegetation.
   see: 1, 3, 10, 27, 29, 36, 63, 64, 84, 95, 98, 99, 103, 105, 107, 110

6. *Establishing water reservoirs*
   Produce hollows to store surplus water during wet periods by decreasing the elevation of the peat surface. This may be achieved by excavating or pushing off peat. Such hollows may also act as growth pools of desired mire species and support the soaking of surrounding areas during periods of drought. This method is technically less complicated and more stable than damming or bunding as it does not raise the water level above its previous position, but it might require a licence from (national) mining law. In some cases upstanding areas might be levelled down to the water level to prevent accidental collapsing and to reduce mineralisation. Consider appropriate areas for the deposition of excavated peat to minimise additional damage.
   Flooding should be deep enough to store enough water for dry periods. Too deep water hampers vegetation establishment.
   Hollows and bunded areas should not be too large to minimise wind and wave erosion.
   see: 1, 3, 10, 59, 61, 64, 98, 103, 107, 110

7. *Introducing surplus water*
   Irrigation by pumping, flooding or diverting of water into the site is very expensive and therefore only possible in small areas of particular interest (small peat remnants or archaeological artefacts) or to kick start initial development.
   Attention should be paid to the quality of introduced water. If restoration aims at establishing nutrient poor conditions, eutrophic water should not be used for rewetting. Water which is rich in sulphates (e.g. river water) should be avoided, as it aggravates peat mineralization and induces internal eutrophication.
   see: 1, 3, 27, 84, 98, 112

8. *Improving water discharge*
   Re-enable infiltration of ground and precipitation water by perforating stagnating (strongly humified and compressed) surficial peat soil horizons.
   see: 11

9. *Reducing evapotranspiration (see 4.2.2)*

10. *Raising catchment water table (see 4.2.3)*

4.2.2 Reduce evapotranspiration by:

1. *Removing trees*

a) Eliminate (part of the) trees from priority sites (e.g. central areas) by cutting or chopping down by hand or by machinery. Ring barking and chemical spraying is an easy method to treat standing trees. Pay attention to safety requirements and plan the treatment of resulting waste.
see: 41, 61, 64, 111, 135

b) Complete removal of cut down waste is desirable (to prevent shading out of low growing species) but very expensive as it requires extra work (and machinery) and careful planning to prevent additional damage.
see: 27

c) Possibilities for less expensive on-site disposal of waste include burning or chipping of wood.
To burn the wood special safety measures are necessary to prevent accidental spreading of fire and damage to existing vegetation.
If the site is wet enough chipped wood might be left on site as it will soon be covered by vegetation. Woodchips might also be used to reduce water losses from drains and ditches.
see: 27

d) In some cases special after treatment (e.g. repeated cutting, weed wiping or painting of stumps) is necessary to prevent re-sprouting of cut down trees.
see: 27, 113 - 115

2. *Planting less evaporating species*
Replace strong evaporating trees by less evaporating trees on the site or in the site's surrounding.

3. *Improving micro climate*
Provide wind shelter by planting trees at marginal areas.
see: 132, 133

4.2.3 Raise catchment water table by:

1. *Decreasing groundwater extraction*
Reduce the intensity of water extraction by limiting the use of water for irrigation and drinking water supply.
see: 26

2. *Increasing infiltration*

a) Change forest composition in adjoining catchment areas.
b) Reduce drainage for agricultural use of adjoining areas.
c) Remove surface sealing.

3. *Slowing down surface run off*

a) Reduce drainage.
b) Replant catchment area.

4. *Increasing rainfall*
Use aerosols (silver iodide or dry ice) to intercept clouds.
see: 116 – 118, 140, 141

5. *Establishing hydrological buffer zones*
see: 10, 16, 107, 119

4.2.4 Reduce water surplus by:

1. *Building more dams upstream to slow down water supply.*
2. *Re-routing incoming water away from focal site.*
3. *Draining off surficial water by ditches or pumping.*
4. *Planting of water consuming species to increase evapotranspiration.*

4.2.5 Provide water of desired quality by:

1. *Reducing impacts on water sources in adjoining areas*
   Prevent water pollution by agricultural activities (fertilizing, liming, pest control) or by industrial or communal waste and waste water.
   see: 6
2. *Filtering water*
   Reduce unwanted substances in incoming water by establishing sediment traps and filters.
3. *Preventing influx of polluted water*
   Keep water of undesired quality away from focal site by re-routing.
   see: 13
4. *Supporting groundwater discharge*
   a) Drain rainwater lenses.
      see: 15, 120
   b) Perforate stagnating surficial peat soil horizons.
      see: 121
   c) Remove stagnating surficial peat soil horizons.
      see: 105
5. *Reducing erosion (see 4.3.4)*

4.3 Peatland restoration to reduce greenhouse gas emissions

The degradation of peatlands is a major and growing source of anthropogenic greenhouse gas emissions. Carbon dioxide emissions from peatland drainage, fires and exploitation are estimated to currently be equivalent to at least 3,000 million tonnes per annum or equivalent to more than 10% of the global fossil fuel emissions. Peatland restoration for reducing greenhouse gas emissions is seen as a very cost-effective measure for long term climate change mitigation and adaptation (Parish et al. 2007). Optimising water management in peatlands (i.e. reducing drainage) is the single highest priority to combat CO_2 emissions from peat oxidation and peatland fires (Parish et al. 2007).

Table 11: Measures to restore peatlands to reduce their climate impact

	What	Why	How
Keep in	**Biomass**	Prevent losses due to damaging activities (incl. harvesting and fire) to maintain *short term* carbon storage by:	Reducing human impact
			Reducing impacts of herbivores
	Water	Prevent too low water levels to limit carbon dioxide (CO_2) emissions or to increase carbon storage by:	Reducing evapotranspiration
			Increasing water level on site
			Raising catchment water table
	Peat	Prevent CO_2 emissions due to aerobic decomposition by:	Increasing water level on site
			Reducing aerobic decomposition
		Prevent CO_2 emissions due to peat erosion by:	Reducing erosion
	N_2O	Increase chemical reduction of nitrous oxide (N_2O) to dinitrogen (N_2) by:	Increasing water level on site
Keep out	**Damage**	Reduce damage to biomass (incl. harvesting) to maintain *short term* carbon storage by:	Preventing (expansion of) fire
			Reducing human impact
			Reducing impacts of animals
	Water	Reduce input of water of undesired quality to prevent emission of CO_2 by:	Providing water of desired quality
	Water	Reduce input of too much water to enable carbon sequestration (peat formation) by:	Reducing water surplus
	Peat extraction	Prevent peat losses due to peat extraction by:	Legislation and licensing
	Fire	Prevent CO_2 emissions due to fire by:	Preventing (expansion of) fire
	Noxious substances	Reduce input of mineralization enhancing substances (lime and nutrients and sulphates via wind or water) by:	Reducing erosion
			Reducing unwanted substances
Get in	**Biomass**	Increase accumulation (esp. carbon storing trees, reeds and mosses) to enhance *short term* carbon storage by:	Introducing focal species
			Improving habitat conditions
	Water	Restore appropriate water levels to reduce peat mineralization by:	Increasing water level on site
			Raising catchment water table
			Reducing evapotranspiration
	Peat	Restore peat formation to enable *long term* carbon sequestration by:	Improving habitat conditions
			Introducing focal species
			Raising catchment water table
			Reducing evapotranspiration
			Increasing water level on site
			Reducing water surplus
Get out	**Species**	Eradicate unwanted (e.g. aerenchymatic) species to reduce methane emissions by:	Suppressing non-focal species
	Water	Prevent too high water levels that hamper peat accumulation and enhance CH_4 production by:	Reducing water surplus
	Noxious substances	Restore adequate levels of fertility (reduce too much nutrients and poisons) to slow down peat mineralization and to support peat forming species by:	Reducing unwanted substances

4.3.1 Re-activate peat formation by:

1. *Reducing aerobic decomposition*
   a) Elevate water levels (see 4.2.1).
   b) Reduce evapotranspiration (see 4.2.2).
   c) Raise catchment water table (see 4.2.3).
   d) Raise water table indirectly by removing degraded surface layers.
   see: 10, 95, 105, 122 - 124
   e) Eradicate deep rooting plants to reduce oxygen penetration of peat.
2. *Supporting existing peat forming vegetation*
   Improve habitat conditions (see 4.1.1).
3. *Re-introducing peat forming species*
   Introduce focal species (see 4.1.3).

4.3.2 Reduce erosion by:

1. *Reducing damage to vegetation and peat surface*
   a) Reduce human impact (on-site and in uplands) (see 4.1.3).
   b) Reduce impact of herbivores (on-site and in uplands) (see 4.1.4).
   c) Prevent preferential flow paths
2. *Stabilizing bare peat surfaces*
   a) Re-vegetate bare areas by introducing focal species (see 4.1.2).
   b) Cover loose and bare areas with adequate material (e.g. geo-jute sheets, nets).
   see: 125, 126
3. *Improving catchment hydrology*
   Provide stable base flow without draught and flood events by raising the catchment water table (see 4.4.3).
4. *Keeping permafrost*
   Re-establish insulating vegetation (see 4.1.1. and 4.1.2).

4.3.3 Reducing noxious substances by:

1. *Harvesting and removing biomass*
   a) Re-establish grazing regime to remove biomass.
   see: 5, 7, 8, 11, 13, 61,127, 128
   b) Establish effective nutrient consuming species to harvest and remove biomass.
   see: 11
2. *Stimulating chemical precipitation*
   Introduce Fe, Ca, NO_3 to precipitate phosphates.
   see: 61
3. *Removing degraded surface layers*
   Cut sods of degraded (polluted, enriched) surface layers.
   see: 5, 6, 11, 13, 15, 61, 120

4.3.4 Prevent (expansion of) fire by:

1. *Limiting access in fire-sensitive periods and to fire sensitive areas*
Reduce human impact (see 4.1.3)

2. *Providing (fire) safety maps*
Locate access routes, unstable ground and water reservoirs.
see: 3, 129, 130

3. *Establishing fire patrolling system*
Engage patrol from ground, watchtowers and air.
see: 129, 130

4. *Establishing fire breaks*
a) Create water filled ditches, trenches.
see: 129, 130
b) Mow or cut aisles into existing vegetation.
see: 10, 84, 129, 130

5. *Providing water for fire fighting*
a) Fill existing depressions with water by damming.
b) Excavate water storing holes.
see: 130

6. *Rewetting peat surface*
a) Elevate water level on site (see 4.2.1)
b) Raise catchment water table (see 4.2.3)

7. *Assessing fire risk*
Develop fire risk models.
see: 31, 129, 130

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