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Annexes to STRP24 Doc.3.1.3 (C): Draft Ramsar Technical Report on Global Guidelines for Peatland Rewetting and Restoration

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Annex I: Values, ecosystem services and restoration targets

The concrete targets of peatland restoration are chosen based on what is needed or wanted, and on what is possible. Restoration can aim for enhancing biodiversity, decreasing fire risk, reducing greenhouse gas emissions, improving water supply, increasing food security, enriching landscape experience, protecting archive values, etc. etc., and these in all possible combinations. Restoration must choose, which targets to pursue, because not all targets can be combined.

Restoration targets can be formulated in terms of 'ecosystem services', i.e. the benefits that people/society may obtain from ecosystems.[1] Ecosystem services do not only include marketable material products, but also a wide range of less tangible values. The table below provides an overview of these services. This table is based on the Common International Standard for Ecosystem Services (CICES), which has been developed on behalf of the European Environment Agency, the United Nations Statistical Division and the World Bank, to systemize the monitoring, valuation and reporting of ecosystem services. The Standard uses three main categories (provisioning, regulating, and cultural services) and divides these into subcategories (Bonn et al. 2016). While these three ecosystem service categories are directly used by human beings, supporting ecosystem services are not directly consumed or enjoyed by people and therefore excluded (Kahn 2020). Examples of supporting ecosystem services include primary production, secondary production, biodiversity, genetic resources, and nutrient cycling.

The term 'ecosystem services' may give the idea that the focus is merely on the 'material' benefits that peatlands may provide, varying from providing food, fodder, fiber and fuel, flood control and denitrification up to regulating climatic conditions. The concept of 'ecosystem services', however, includes a much wider range of values and includes all relationships relevant for humans and humanity.
Ecosystem services are sometimes confused with biodiversity. Biodiversity is not itself an ecosystem service but rather underpins the supply of ecosystem services. The value some people place on biodiversity for its own sake is captured under the cultural ecosystem services as spiritual, aesthetic or educational values. Other ecosystem services closely associated with biodiversity include food, genetic resources, timber, biomass fuel, recreation, and ecotourism.

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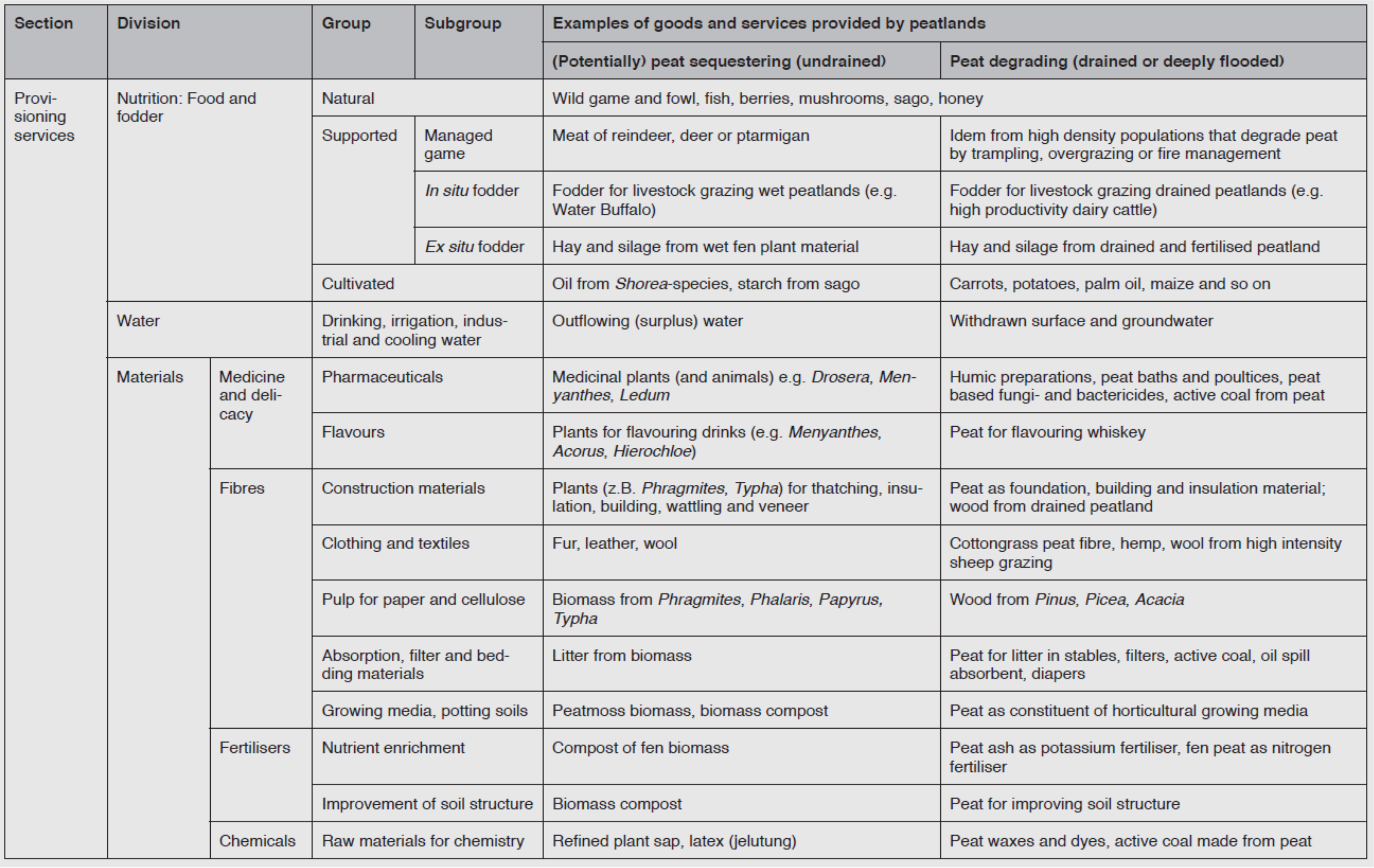
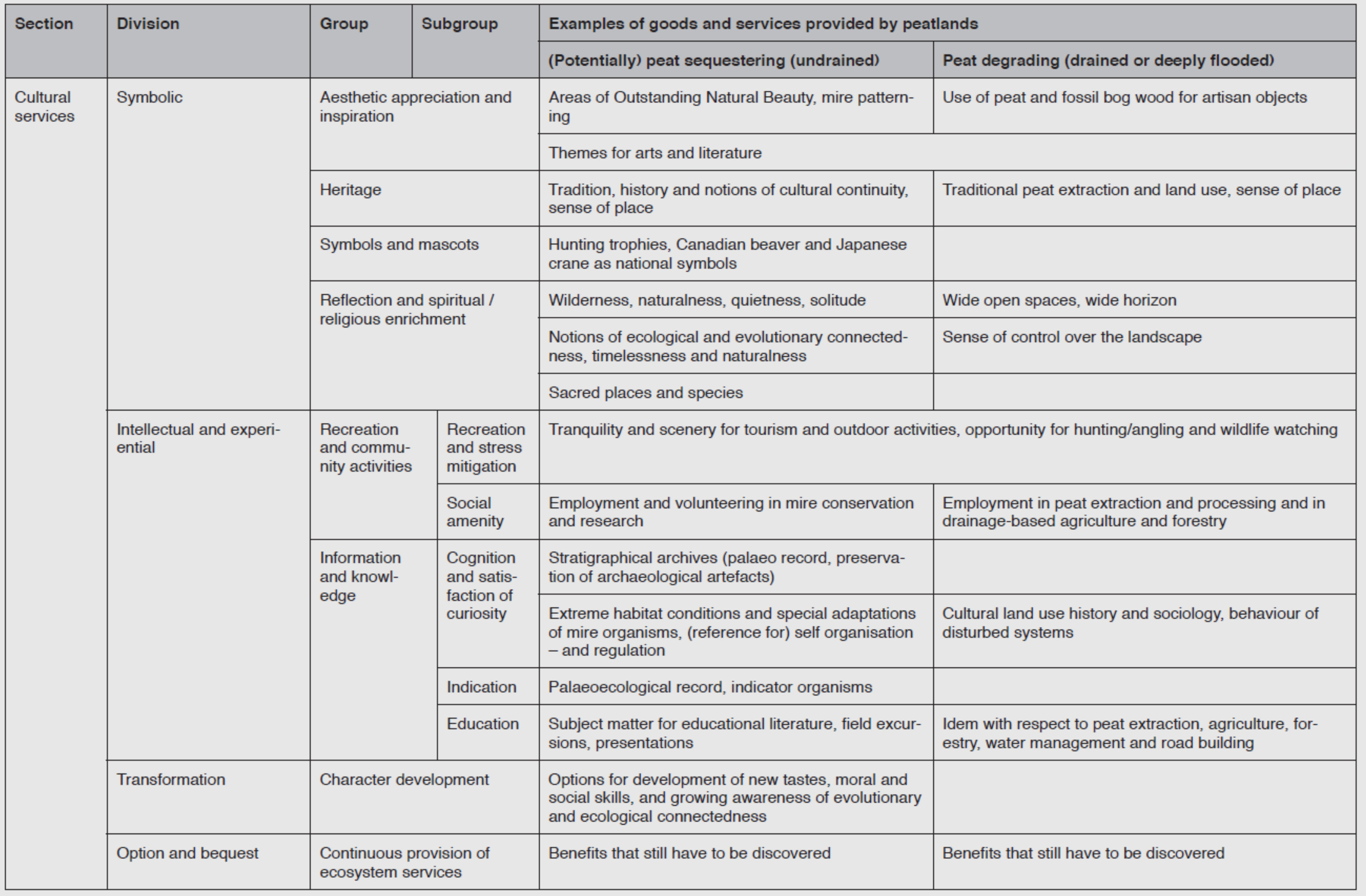
[1] In the context of climate change politics, ecosystem services are also called 'nature's contributions to people' (Diaz et al. 2018, de Groot et al. 2018).

Table 1: Peatland ecosystem services according to the Common International Standard for Ecosystem Services (CICES), as adapted for peatlands (Joosten 2016)



Section	**Division**		**Group**	**Subgroup**	**Examples of goods and services provided by peatlands**	
					(Potentially) peat sequestering (undrained)	**Peat degrading (drained or deeply flooded)**
Provisioning services	Nutrition: Food and fodder		Natural		Wild game and fowl, fish, berries, mushrooms, sago, honey	
			Supported	Managed game	Meat of reindeer, deer or ptarmigan	Idem from high density populations that degrade peat by trampling, overgrazing or fire management
				In situ fodder	Fodder for livestock grazing wet peatlands (e.g. Water Buffalo)	Fodder for livestock grazing drained peatlands (e.g. high productivity dairy cattle)
				Ex situ fodder	Hay and silage from wet fen plant material	Hay and silage from drained and fertilised peatland
			Cultivated		Oil from *Shorea*-species, starch from sago	Carrots, potatoes, palm oil, maize and so on
	Water		Drinking, irrigation, industrial and cooling water		Outflowing (surplus) water	Withdrawn surface and groundwater
	Materials	Medicine and delicacy	Pharmaceuticals		Medicinal plants (and animals) e.g. *Drosera, Menyanthes, Ledum*	Humic preparations, peat baths and poultices, peat based fungi- and bactericides, active coal from peat
			Flavours		Plants for flavouring drinks (e.g. *Menyanthes, Acorus, Hierochloe*)	Peat for flavouring whiskey
		Fibres	Construction materials		Plants (z.B. *Phragmites, Typha*) for thatching, insulation, building, wattling and veneer	Peat as foundation, building and insulation material; wood from drained peatland
			Clothing and textiles		Fur, leather, wool	Cottongrass peat fibre, hemp, wool from high intensity sheep grazing
			Pulp for paper and cellulose		Biomass from *Phragmites, Phalaris, Papyrus, Typha*	Wood from *Pinus, Picea, Acacia*
			Absorption, filter and bedding materials		Litter from biomass	Peat for litter in stables, filters, active coal, oil spill absorbent, diapers
			Growing media, potting soils		Peatmoss biomass, biomass compost	Peat as constituent of horticultural growing media
		Fertilisers	Nutrient enrichment		Compost of fen biomass	Peat ash as potassium fertiliser, fen peat as nitrogen fertiliser
			Improvement of soil structure		Biomass compost	Peat for improving soil structure
		Chemicals	Raw materials for chemistry		Refined plant sap, latex (jelutung)	Peat waxes and dyes, active coal made from peat

Section	Division	Group	Subgroup	Examples of goods and services provided by peatlands	
				(Potentially) peat sequestering (undrained)	Peat degrading (drained or deeply flooded)
Provi-sioning services (cont.)	Fuel	Fossil fuel		Marsh gas (methane)	Peat and peat-derived fuels
		Biomass based fuel		Reed, sedges, wood	Palm oil, maize for biogas production, wood, sugar cane for alcohol production
	Space	… for biomass provision		(See nutrition, materials and fuel)	(See nutrition, materials and fuel); fish ponds
		... for urban, industrial and infrastructural development		Space for some wind farms, some transport infrastructure	Space for settlements, harbours, airports, industry complexes, hydro-electricity reservoirs, landfills
		… for defence and isolation		Space for low intensity military training grounds	Space for high intensity military training grounds
				Little managed defence and border lines	Intensively managed defence and border lines
				Space for prisons and labour camps	Associated peatland drainage and reclamation
Regulating services	Regulation of waste	Bioremediation		Denitrification, nutrient retention and sequestration in plants and peat	Wastewater treatment, intensive denitrification
		Dilution and sedimentation tation		Clean water supply to dilute downstream pollution, filtering out of pollutants	-
	Regulation of flows	Regulation of water flow		Attenuation of run-off and discharge rates, mitigation of downstream floods	
				Maintenance of base flow, coastal protection	Rapid discharge and increased buffer capacity after drainage
		Regulation of mass flow		Erosion control	
	Regulation of the physical environment	Global climate		Carbon sequestration and storage in peat	Idem in biomass and litter in some boreal peatland forests (temporarily)
		Local and regional climate		Evapotranspiration cooling	
		Water quality		Nutrient retention, denitrification	Waste treatment, denitrification
		Soil conditions		Peat accumulation, initiation and conservation of permafrost	Improved soil structure through secondary pedogenesis, conservation of permafrost
	Regulation of the biotic environment	Life cycle maintenance and habitat protection		Pollination, seed dispersal	
				Wildfire control	
		Pest and disease control		Control of pathogens and invasive species	
		Gene pool protection		Rare and specialised mire and wetland species	Rare species of (slightly) drained fen meadows



Section	Division	Group	Subgroup	Examples of goods and services provided by peatlands	
				(Potentially) peat sequestering (undrained)	Peat degrading (drained or deeply flooded)
Cultural services	Symbolic	Aesthetic appreciation and inspiration		Areas of Outstanding Natural Beauty, mire patterning	Use of peat and fossil bog wood for artisan objects
				Themes for arts and literature	
		Heritage		Tradition, history and notions of cultural continuity, sense of place	Traditional peat extraction and land use, sense of place
		Symbols and mascots		Hunting trophies, Canadian beaver and Japanese crane as national symbols	
		Reflection and spiritual / religious enrichment		Wilderness, naturalness, quietness, solitude	Wide open spaces, wide horizon
				Notions of ecological and evolutionary connectedness, timelessness and naturalness	Sense of control over the landscape
				Sacred places and species	
	Intellectual and experiential	Recreation and community activities	Recreation and stress mitigation	Tranquility and scenery for tourism and outdoor activities, opportunity for hunting/angling and wildlife watching	
			Social amenity	Employment and volunteering in mire conservation and research	Employment in peat extraction and processing and in drainage-based agriculture and forestry
		Information and knowledge	Cognition and satisfaction of curiosity	Stratigraphical archives (palaeo record, preservation of archaeological artefacts)	
				Extreme habitat conditions and special adaptations of mire organisms, (reference for) self organisation – and regulation	Cultural land use history and sociology, behaviour of disturbed systems
			Indication	Palaeoecological record, indicator organisms	
			Education	Subject matter for educational literature, field excursions, presentations	Idem with respect to peat extraction, agriculture, forestry, water management and road building
	Transformation	Character development		Options for development of new tastes, moral and social skills, and growing awareness of evolutionary and ecological connectedness	
	Option and bequest	Continuous provision of ecosystem services		Benefits that still have to be discovered	Benefits that still have to be discovered

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Annex II: Hydrogenetic mire types

Hydrogenetic mire classification focusses on the processes that drive peat formation and peatland development. Special attention is paid to the interrelations and feedback mechanisms between i) water flow and fluctuations, ii) vegetation, and iii) peat formation, and to the role peatland development plays in landscape hydrology. The following text is largely based on Joosten et al. (2017), where also ample references can be found.

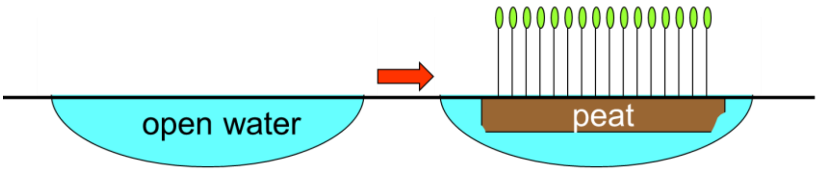
Hydrogenetic mire types consist of two major groups: the ‘horizontal mires’ and the ‘inclining (sloping) mires’ (Table 1).

HORIZONTAL MIRES occur in closed basins, where horizontal water movement is largely prevented by a flat relief and impervious substrates, and the water surface is therefore horizontal. Vertical (seasonal or inter-annual) water table fluctuations can be small to very large. Peat formation only occurs if the periods of waterlogging are much longer than the dry periods, so that oxidative losses are exceeded by the production of organic material. Horizontal mires have almost no influence on water flow in the landscape or on the water table of their surroundings. Their effect on landscape hydrology is merely that they diminish basin water storage as they fill the basins up with peat, which may lead to a larger (near-)surface peak flow elsewhere in the landscape.

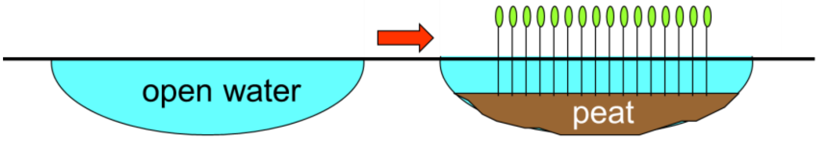
Horizontal mires are subdivided into:

- ‘**Terrestrialisation mires**’, where peat formation takes place in or over ‘open’ water. Terrestrialisation mires are subdivided into:
  - ‘Schwingmoor mires’ in which peat accumulates in a floating mat; and
  - ‘Immersion mires’ in which peat accumulates on the bottom of the water body.

  The peat deposited at the start of terrestrialisation is mostly weakly decomposed. As the basin fills up with continued terrestrialisation, the more recently deposited upper peat layers are subject to stronger decomposition because of increasing water table fluctuations. At the end of the terrestrialisation process, when the basin is completely filled, peat accumulation stops unless another peat formation strategy takes over.



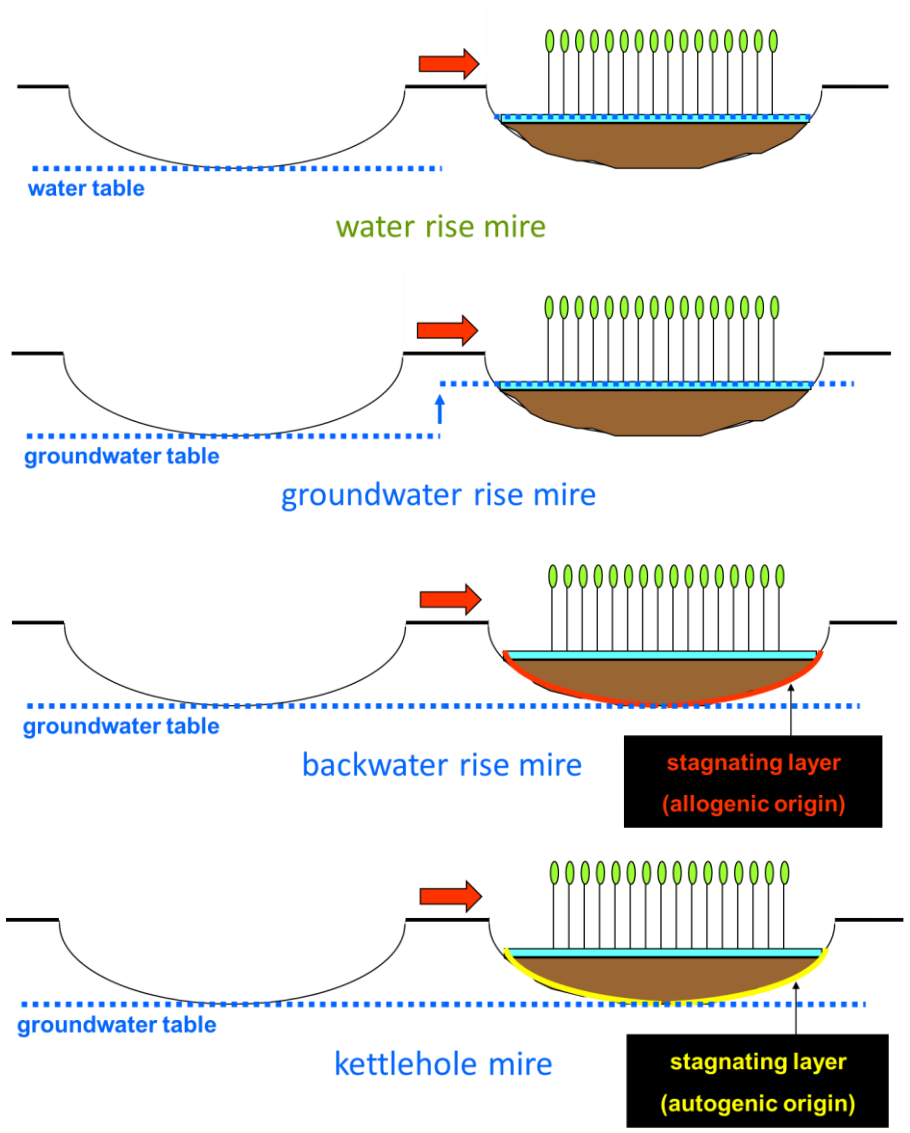
schwingmoor terrestrialization mire



immersion terrestrialization mire

- ‘**Water rise mires**’, where peat formation takes place following a rising water table (that is insufficient to create open water, see above). As water depth (above the surface) is mostly small and water table fluctuations are usually large, strongly decomposed peats are deposited that have a low hydraulic conductivity and only a small storage coefficient, but high capillarity. Water rise mires are subdivided into:

- ‘Groundwater rise mires’ in contact with and fed by the catchment groundwater;
- ‘Backwater rise mires’ without groundwater contact, fed by interflow, and with allogenic sealing; and
- ‘Self-sealing mires’ without groundwater contact, fed by interflow, and with autogenic sealing (“self-sealing”).

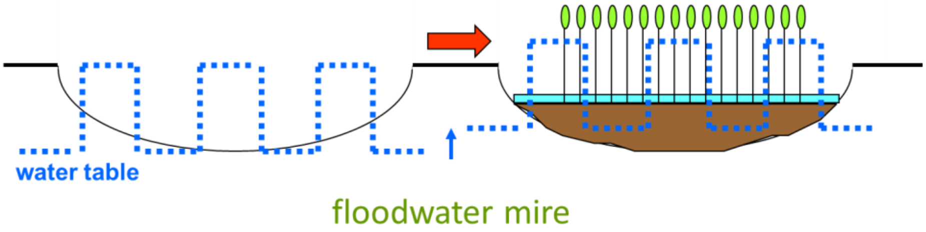


A rise in the groundwater level may occur regionally (e.g. because of sea level rise, a change in climate or land use, or because of peat formation in lower lying valleys). A relative rise in groundwater level may also result from tectonic or glacialisostatic landfall or karst breaches.

In depressions without connection to the groundwater, the water table may rise locally because less water infiltrates due to sealing of the subsoil by mineral or organic particles (hardpan, B horizons of podsol soils), or because less water is lost laterally (for example due to beaver dams or mill weirs, or because more water flows into the depression (for example due to reclamation or soil compaction in the catchment).

A particular subtype of water rise mires is the 'self-sealing mire'. Self-sealing mires themselves form a stagnating layer in the previously more permeable mineral subsoil, usually in a kettle shaped basin. As water outflow is impeded to a higher and higher level, the mire internal water table rises. Although the sealing occurs under the influence of flowing water that transports the humus colloids responsible for the sealing from the mire to the mineral subsoil, the peat accumulation strategy is that of a mire without substantial lateral water flow.

- '**Floodwater mires**', which are bound to periodically flooded areas. The water surplus usually runs off fast. Floodwater mires are subdivided into:
  - 'River floodwater mires', where regular flooding is caused by (annual/subannual) water pulses from the catchment area;
  - 'Marine floodwater mires', where regular flooding is caused by lunar tides (e.g. peat accumulating mangroves and saltmarshes); and
  - 'Lake floodwater mires', where regular flooding is caused by wind tides (e.g. large lakes, Baltic Sea).



Usually floodwater mires have strongly decomposed peats because of strong water table fluctuations. Floodwater mires with a substantial peat thickness can only occur if (relative) water tables are rising (rising sea water level, rising river beds, etc.). As such they are related to water rise mires. The difference is the mechanical action of periodic lateral water flow and associated sedimentation of allogenic clastic materials (sand, clay). As a rule, mire surface oscillation does not occur, because of the high bulk density of the peat. As the hydraulic conductivity of the peat is low, surface run off is high, although it is somewhat retarded by the vegetation. With this influence on lateral water flow this type forms the transition to the group of inclining mire types.

Horizontal mires are 'passive': they lie horizontally in the landscape, water movement is largely vertical, and they have no (or only a very limited) hydrologic influence on the catchment area. Over time, as their basins gradually fill with peat, they reduce the water storage capacity of the landscape.

INCLINING MIRES are more ‘active’: the mire surface shows a slope and a significant amount of water is lost through lateral flow. The vegetation and the peat retard this flow and so vegetation growth and peat accumulation lead to an absolute rise in water table, in the mire and often also in the catchment, with continued accumulation of peat as a result. In contrast to horizontal mires, inclining mires enlarge the water retention of the landscape.

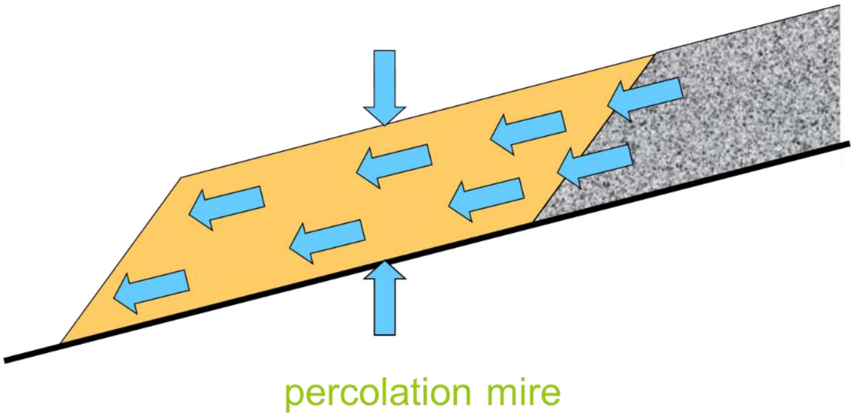
Inclining mires can regulate the water available to them to some extent. Most importantly, they retard its run off, but they also discharge surplus water effectively over the surface because of their slope. In regulating water in- and outflow, the dynamic triangular relationship between water, vegetation, and peat plays an important role. Inclining mires are subdivided into:

- ‘**Percolation mires**’, which are bound to landscapes where water supply is large and very evenly distributed over the year. As a result, the water table in the mire is almost constant relative to the surface. Dead plant material reaches the permanently waterlogged zone quickly and is subject to fast aerobic decay only for a short time. Consequently, the peat remains weakly decomposed and elastic. Because of the large pores and the related high hydraulic conductivity, a substantial water flow occurs over a substantial depth of the peat body. Whereas young percolation mires are susceptible to externally induced water table fluctuations, the growing peat thickness over time increasingly compensates for fluctuations in water supply and water losses by mire surface oscillation. The peat’s ability to oscillate makes conditions for peat formation at the surface increasingly stable. Percolation mires are subdivided into:

    - ‘Percolation fens’, fed by groundwater (geogenous); and

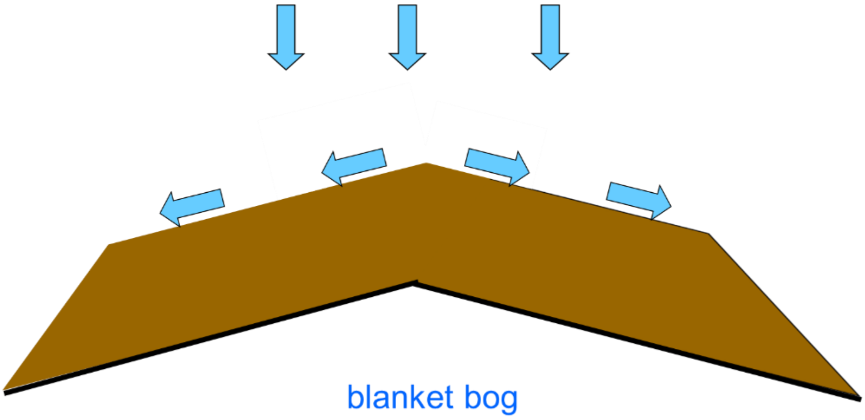
    - ‘Percolation bogs’, only fed by precipitation (ombrogenous).

  Only large catchment areas can guarantee a large and continuous water supply in most climates. Therefore percolation mires are normally only found as groundwater-fed mires (fens). In the Colchis area (Georgia), however, *Sphagnum*-dominated ombrogenous percolation mires (bogs) exist under conditions of almost ‘constant’ heavy rainfall.

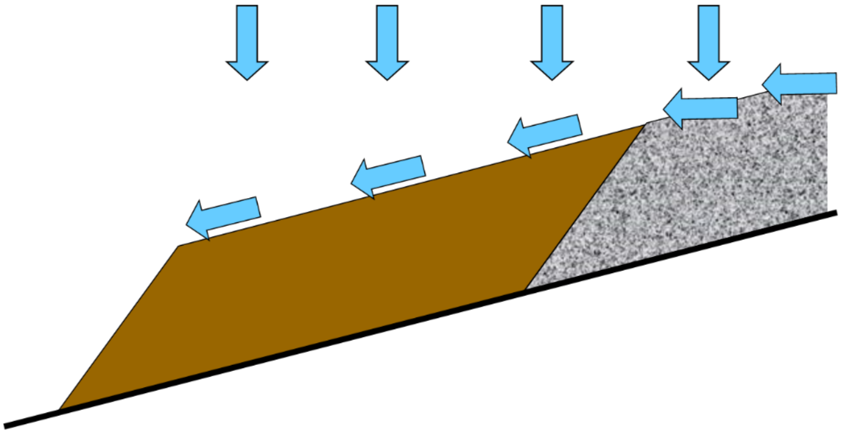


- ‘**Surface flow mires**’, where strong peat decomposition forces the water to overflow the peat. Surface flow mires can only endure if oxidative losses are limited, i.e. if the water table drops only rarely. They are therefore limited to areas with almost constant water supply over the year and/or with only little water losses (especially due to evapotranspiration). Because of the small storage coefficient of the peat, any water shortages may still lead to rather large drops in the water table (and resulting strong peat decomposition). Because of their low hydraulic conductivity and large water supply, overflow mires may occur on and with steep slopes. Surface flow mires are subdivided into:

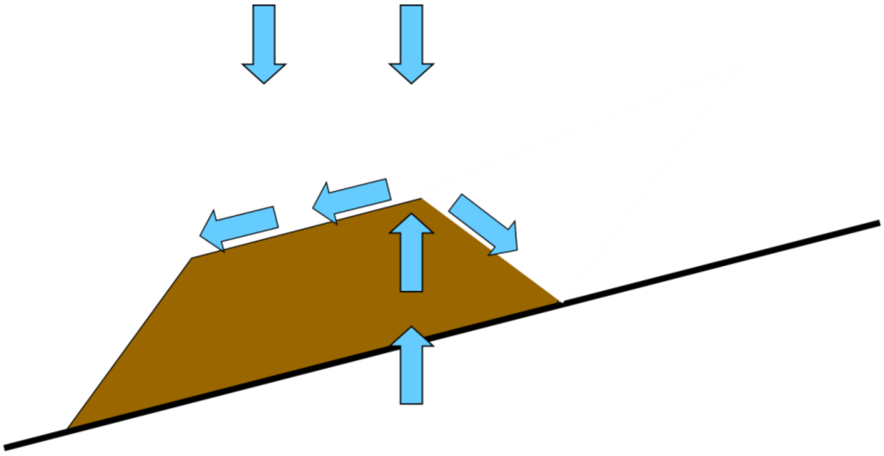
  - ‘Blanket bogs’, only fed by rainwater;
  - ‘Hill slope mires’, also fed by surface run-off; and
  - ‘Spring mires’, also fed by groundwater.



blanket bog



hill slope mire

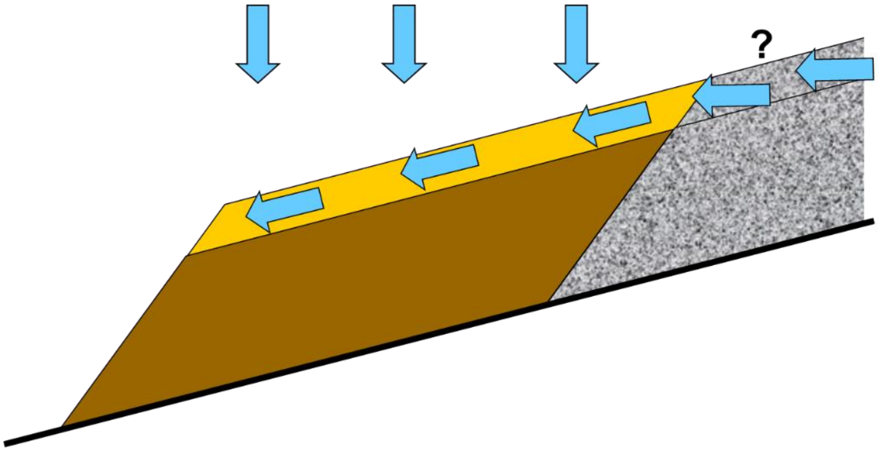


spring mire

- ‘**Acrotelm mires**’, which show a distinct vertical gradient in hydraulic conductivity in their vegetation layer and near surface peat that allows them to regulate water flow and limit water losses. Acrotelm mires are only know as ombrotrophic ecosystems (= only fed by rain) but theoretically also groundwater fed systems are imaginable (indicated with a ? in the figure below).

Sphagnum acrotelm mires ('raised bogs') are characterised by a continuous accumulation of fresh *Sphagnum* material that combines a high storage coefficient (many and large pores) with a small decayability of the material. This limited decayability keeps the effect of water table fluctuations on pore space relatively small. Water losses by run-off and evapotranspiration cause only limited water table drop-downs because of the large pores and the large storage coefficient of the peat. The distinct vertical gradient in pore space and hydraulic conductivity results from the deeper, older peat material having longer been prone to oxidation and to pressure. If the water table does drop in times of water shortage, only little water can flow off through the less permeable part of the 'acrotelm'. In this way, the deeper peat layers (the 'catotelm') remain continuously waterlogged, even if water supply varies.

In case of the *typus classicus* of acrotelm mires, the *Sphagnum* dominated raised bog, the contrasting requirements of a large storage coefficient (to prevent large water table drops by evapotranspiration losses) and a small hydraulic conductivity are only fulfilled by a handful of *Sphagnum* species, first and foremost *Sphagnum austinii*, *S. fuscum*, *S. magellanicum/medium/divinum*, *S. papillosum*, and *S. rubellum/capillifolium*. These species combine a limited decayability with favourable nutrient poor and acidic conditions, inherent to ombrotrophic conditions. The surprisingly wide distribution of the *Sphagnum* acrotelm mire type shows the effectiveness of this strategy.



acrotelm mire

Also the tropical domed peat swamp forests in SE Asia (and probably also elsewhere in the Tropics) are acrotelm mires. Here the lowermost part of the forest vegetation, the litter layer and the ground surface structure realizes the typical conductivity gradient that keeps the wet season water longer in the mire.

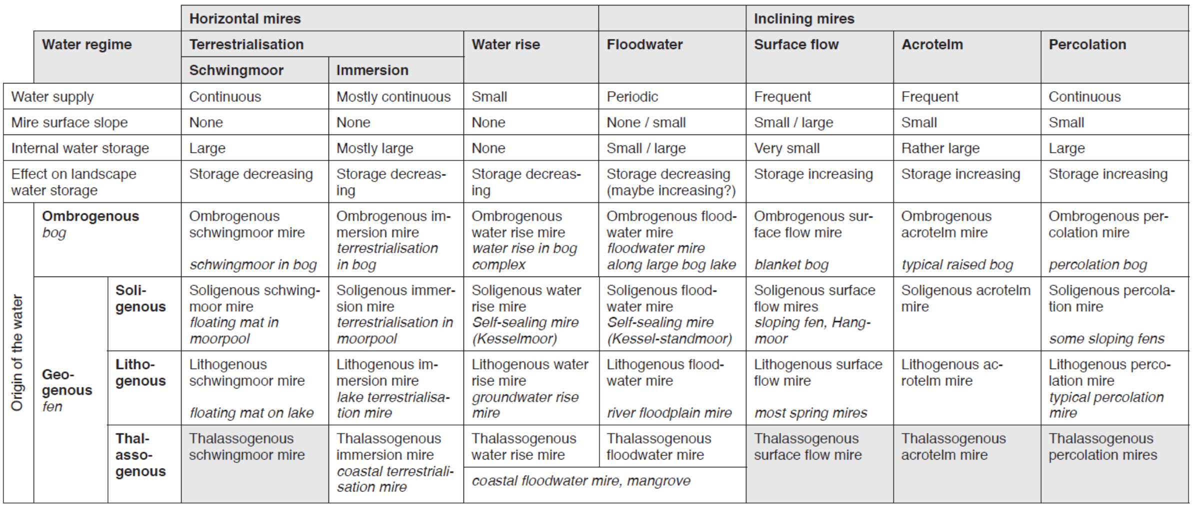
The hydrogenetic peat formation types can be combined with other variables, e.g. with:

- the origin of the water;
- water quality
- vegetation, etc.

As an example we present a combination with the origin of the water (see table 1):

- ombrogenous: stemming solely from precipitation water;
- soligenous: also stemming from surficial run-off;
- lithogenous: also stemming from deep groundwater and
- thallasogenous: also stemming from seawater.

Table 1: Hydrogenetic mire types (columns) combined with their hydrological properties and the origin of the water (rows), with examples in *italics*. Grey fields denote combinations that are probably not existing (Joosten et al. 2017).



			Horizontal mires				**Inclining mires**		
	Water regime		**Terrestrialisation**		**Water rise**	**Floodwater**	**Surface flow**	**Acrotelm**	**Percolation**
			Schwingmoor	**Immersion**					
Water supply			Continuous	Mostly continuous	Small	Periodic	Frequent	Frequent	Continuous
Mire surface slope			None	None	None	None / small	Small / large	Small	Small
Internal water storage			Large	Mostly large	None	Small / large	Very small	Rather large	Large
Effect on landscape water storage			Storage decreasing	Storage decreasing	Storage decreasing	Storage decreasing (maybe increasing?)	Storage increasing	Storage increasing	Storage increasing
Origin of the water	**Ombrogenous** *bog*		Ombrogenous schwingmoor mire *schwingmoor in bog*	Ombrogenous immersion mire *terrestrialisation in bog*	Ombrogenous water rise mire *water rise in bog complex*	Ombrogenous floodwater mire *floodwater mire along large bog lake*	Ombrogenous surface flow mire *blanket bog*	Ombrogenous acrotelm mire *typical raised bog*	Ombrogenous percolation mire *percolation bog*
	Geogenous *fen*	**Soligenous**	Soligenous schwingmoor mire *floating mat in moorpool*	Soligenous immersion mire *terrestrialisation in moorpool*	Soligenous water rise mire *Self-sealing mire (Kesselmoor)*	Soligenous floodwater mire *Self-sealing mire (Kessel-standmoor)*	Soligenous surface flow mires *sloping fen, Hangmoor*	Soligenous acrotelm mire	Soligenous percolation mire *some sloping fens*
		Lithogenous	Lithogenous schwingmoor mire *floating mat on lake*	Lithogenous immersion mire *lake terrestrialisation mire*	Lithogenous water rise mire *groundwater rise mire*	Lithogenous floodwater mire *river floodplain mire*	Lithogenous surface flow mire *most spring mires*	Lithogenous acrotelm mire	Lithogenous percolation mire *typical percolation mire*
		Thalassogenous	Thalassogenous schwingmoor mire	Thalassogenous immersion mire *coastal terrestrialisation mire*	Thalassogenous water rise mire *coastal floodwater mire, mangrove*	Thalassogenous floodwater mire	Thalassogenous surface flow mire	Thalassogenous acrotelm mire	Thalassogenous percolation mires

As a result of interactions of vegetation, water, and peat ('self-organisation'), mires develop various morphological types. These consist of a characteristic landform (cross-sectional profile, Grossform) combined with characteristic configurations of microtopographic surface-elements (Kleinform).

Classical examples are kermi bogs (an acrotelm mire) and aapa mires (a surface flow mire).

In inclining mires, ice development leads to a stronger differentiation between, and a more explicit arrangement of, positive and negative microrelief elements (hummock and hollows, strings and flarks etc.). This results in the development of 'concentric' and 'eccentric bogs' and of 'ribbed fens'/aapa mires.

Next to internal processes, also external processes, such as fluvial and frost activity, may be important in the configuration of peatland macro- and micro-structures. Frost activity may lead to features that also exist in mineral soils but which, in case of peat-covered areas, give rise to specific morphologic peatland types, such as 'palsa', 'peat plateau' and 'polygon' mires.

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Annex III: Conflicts, trade-offs and synergies

Peatland rewetting and restoration aim at multiple ecological, social, and economic functions and a range of ecosystem goods and services for multiple stakeholder groups. Some services are synergistic and reinforcing, others are potentially conflicting (Acreman et al. 2011). This annex considers the main conflicts and synergies.

Most important conflicts are:

- waterborne diseases: rewetting may increase the incidence of vectors of waterborne diseases, both for livestock and humans (Cromie et al. 2012),
- nuisances to surroundings: loss of familiar landscape, flooded cellars, biting midges, mosquitos (Becker et al. 2010, Verdonschot & Besse-Lototskaya 2014, Hawkes et al. 2020),
- in- and external eutrophication: rewetting with surface water may lead to nutrient input and sulfate-induced phosphate mobilisation (Lamers et al. 2002). Rewetting, especially of nutrient-rich, former agricultural land, may lead to the (temporary) mobilisation of nutrients (Haapalehto et al. 2014, Kotowski et al. 2016), particularly phosphate, which can eutrophicate the site itself as well as downstream waters (Sallantaus 2014, Harpenslager et al. 2015, Zak et al. 2018). Risks and mitigation options are discussed in Zak et al. (2010). The leaching of nutrients and suspended solids can be reduced by diverting water from the drainage ditches to be blocked onto the surrounding peatland (Rehell et al. 2014).
- methane emissions: rewetting not only stops the emissions of CO_2 and N_2O (Wilson et al. 2026), but also re-installs the generation and emission of the potent greenhouse gas methane (see § 4.2),
- destruction of historical, archaeological and palaeoecological values (Joosten 1987, Similä et al. 2014, Waylen et al. 2016). Conflicts can be minimized by prior inventory (cf. Coles 1995, Coles et al. 2001, Greiser & Joosten 2018), by involving specialists in management planning and regular monitoring (Thom et al. 2019), and by providing information to the executing personnel about valuable sites and how they should be considered during restoration work.
- Impairment of existing species conservation values. Mitigation options include minimising damage to remnants and refugia by redistributing the risks through timing, modifying restoration techniques, and creating alternative (and functional!) habitats for the species involved (Remm et al. 2019).
- The fundamental conflict between ‘making’ and ‘becoming’: design annihilates spontaneity - “creation destroys nature” (see § 4.3).

Synergies:

- Diseases: Felling conifer forest to restore peatlands may produce a dramatic decline in tick abundance with implications for reduced disease risk (Gilbert 2013).
- Archaeology/archive value: Generally, the protection of palaeo-values is favoured by measures that stabilise peat and reduce erosion, halt the physical removal of peat, maintain high water tables, and promote active peat formation[2] (Brunning et al. 2000, 2012, Gearey & Fyfe 2016).

Goal-setting should weigh the desired outcomes against the risks of failure, specifically if a ‘degraded’ ecosystem already contains high-value components. Where there is large uncertainty, it may be wiser to retain present values, even if restoration *might* achieve greater benefits over the longer term. Joosten & Van Noorden (1992) present a valuation system for all kinds of natural and cultural elements by combining spatial diversity (how rare is the element locally, nationally, globally) and temporal development (does development takes years, centuries or millennia). On the basis of this integrated valuation they provide

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[2] https://www.ramsar.org/document/resolution-viii19-guiding-principles-for-taking-into-account-the-cultural-values-of

guidelines for deciding between actual and potential elements. When actual and potential elements are of the same value, actual values should prevail over potential ones (“one bird in the hand is better than ten birds on the tree”). If the potential values are of a higher category than the actual ones, a ‘gamblers’ mentality enters the scene. If you consider a 50 % probability for a jump between two successive categories acceptable (i.e. from 8 to 7, or from 5 to 4), you could jump from a cat. 8 value to a cat. 3 value with a realisation probability of 0.5 x 0.5 x 0.5 x 0.5 x 0.5 = 0.03 (3%).

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Annex IV: Public participation and stakeholder involvement

Successful implementation of a restoration project will often depend on public support and acceptance, not in the least from the local community and local stakeholders. Public participation is essential, particularly if substantial reservations towards the planned project are to be expected. The Aarhus Convention requires that opportunity is given for public participation in decisions about developments that may have a significant effect on the environment[3].

"For restoration measures to succeed on tropical peatlands, they must be conducted in collaboration with local communities. This is because communities who currently depend upon peatlands for meeting their livelihood needs may destroy restoration efforts that they perceive not to be in their interests. Examples of how they may do this include illegal forest felling, the use of fire to promote agriculture in degraded forests, or the destruction of dams designed to slow peatland drainage. Significant and appropriate incentives are therefore needed to persuade local communities to substitute peat degradation-based income earning strategies with alternative livelihood opportunities that have limited impacts on tropical peat ecology and hydrology." (Jewitt 2008)

Increasing intensities of public participation include:

- providing information, e.g. using leaflets, brochures, posters, stickers, calendars, newsletters, unstaffed exhibits, advertisements, articles in public newspapers, radio or television comments, videos / DVDs, social media, organised site visits (also for journalists)…

- collecting feedback, e.g. via responding staff at public exhibitions, social media, staffed telephone lines, regularly updated websites and blogs, telephone / online conferences, project presentations and public meetings…

- involving in decision making (consultation), e.g. via workshops, forums, open houses (also in the field and on the internet, e.g. with bulletin boards, mailing lists, discussion forums)
- enabling to decide, e.g. via community advisory committees, 'planning for real' or 'citizens' juries' with local groups or representative jurors participating in project planning, Free and Prior Informed Consent (FPIC[4]).

In 2017, the USAID-funded LESTARI project supported a **Free, Prior and Informed Consent** (FPIC) process for developing canal blocks in five villages within the C-2 block (55,733 hectares) of the former Mega-rice Project Area in Central Kalimantan, Indonesia. The work involved local governments and communities, the Peatland Restoration Agency (BRG) and the Water Management Centre. Of the five villages engaged, one village declined to have canals blocked while four villages agreed to build canal blocks with BRG funding. FPIC facilitation ensured that communities were well informed about canal blocking, had an opportunity to provide inputs, and gave their willing consent to construct, maintain, and protect the dams. Notably, local communities were able to influence the design of dams so that their small boats can pass through spillways in order to maintain their livelihoods.

In total 178 canal blocks were successfully constructed between 2017 and 2018. After the construction of the blocks, the number of fire hotspots within the C-2 area decreased from 944 hotspots in 2015 to 1 hotspot in 2018. The construction of the canal blocks provided increased production of fish in canals that were blocked - providing economic benefits. Community involvement at the site level has resulted in well maintained canal blocks (compared to adjacent areas where communities were not engaged

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[3] UNECE Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters (Aarhus Convention) https://www.unece.org/env/pp/treatytext.html

and many blocks have failed). Given the social and economic complexity of peatland restoration, canal blocking engaging communities through FPIC method and in construction is advocated (Parish et al. 2019).

PROMOTE participation:

- meet people at regularly visited places
- involve different communities
- spread information by different media (social media, newspapers, television, radio, internet)
- distribute materials in local language(s)
- engage interpreters and moderators
- train staff in cultural awareness, anti-racism and equal opportunity
- create a community atmosphere (guided field trips, action days, exhibitions, and presentations)
- offer refreshments, tea and biscuits, fruits
- provide encouragements (e.g. prizes or gifts)

Relevant guidance can be found in:

- the Ramsar Communication, Education, and Public Awareness Programme (CEPA)[5]
- the Convention of Biological Diversity CEPA Toolkit[6]:
- Frogleaps[7]

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[5] http://www.ramsar.org/activity/the-ramsar-cepa-programme
[6] https://www.cbd.int/cepa/toolkit/2008/cepa/index.htm
[7] www.frogleaps.org

Annex V Notes on vegetation management

Seeding and transplantation

After the hydrologic conditions have been restored (see § 6.3), the chance that characteristic fen communities will spontaneously re-establish depends on:

- the length of time the fen has been drained (which next to the quality of the seed bank also determines how degraded the topsoil is and whether top soil removal should be considered),
- the plant species present within the re-wetted area,
- the proximity of extant fen habitat with the desired species.

The seed bank of characteristic fen species is only short-lived and will not have survived long-term drainage, plowing or top soil removal. Seed dispersal of relevant species is generally bad, so that colonisation from nearby fens is unlikely unless vegetative fragments and seeds can float into the receptor site. Only wetland plants with effective dispersal by wind or waders and ducks immigrate rapidly (Pfadenhauer & Grootjans 1999, Mälson et al. 2008, McBride et al. 2011, Hedberg et al 2012, Lamers et al 2015, Klimkowska et al. 2019).

In case the desired species do not establish spontaneously, re-introduction can be considered (Hedberg et al. 2012), e.g. by direct seeding, hay transfer, planting pre-grown seedlings, transplanting sods from nearby donor fens, planting pre-grown plugs or species grown on geotextile matting, or even by actively transporting a complete fen (Mälson et al. 2008, Ramseier et al. 2009, McBride et al. 2011, Kiehl et al. 2014, Lamers et al. 2015, Wilhelm et al. 2015, Chimner et al. 2017, Pedrini & Dixon 2020).

Hay transfer is cheap and effective for both vascular plants and bryophytes, whereas local hay guarantees adaptation to the local climate (Pfadenhauer & Grootjans 1999, Patzelt et al. 2001). Turf replanting uses the feature that most fen plant species spread vegetatively by rhizomes. Fen mosses may well regenerate from fragments (Malson & Rydin 2007). For most species, a closed vegetation mat of highly competitive species is a major constraint to establishment (Van Dijk et al. 2007).

Taylor et al. (2018) present an overview of actions (and their effects) that complement planting, such as adding of lime, fertilizer, organic fertilizer, or organic mulch.

The aim of many restoration projects in Europe is to re-establish ‘fen meadows’. Fen meadows are slightly drained, groundwater-dependent fen ecosystems, which have usually lost the ability to accumulate peat but as a result of the long-term, low-intensity agricultural management have acquired a high biodiversity density of typical fen species. Fen meadows are restored by (i) raising water levels by closing drainage ditches, (ii) removing excess nutrients by long-term mowing or topsoil removal, (iii) re-introducing target species, and (iv) restoring traditional management (Klimkowska et al. 2014). In contrast, fen restoration in North America focusses more on the peatland’s natural state.

Restoring traditional management

Traditionally, many of the naturally open fens in Western-Europe and Eastern-Asia were mown and grazed for fodder and litter (and often slightly drained), which in spite of its low-intensity resulted in compaction of the uppermost peat. As long as hay making and grazing persisted, the formation of rainwater lenses was prevented by tread regularly bringing the surface in contact with buffering groundwater. Furthermore, regular biomass removal suppressed competition and inhibited the establishment of trees and shrubs that would result from the stronger fluctuating water levels (Schipper et al. 2007). After use has been abandoned, the fens currently suffer under heavy losses in typical species diversity, a decrease in bryophyte cover, a dominance of some graminoid species, and tree and shrub encroachment (Kozub et al. 2018).

The former vegetation can be restored through intensive mowing (Middleton et al. 2006, Hájková et al. 2009). This may, however, also lead by the destruction of microtopography to a loss of rare fen species (Kotowski et al. 2013) and enhance acidification (van Diggelen et al. 2015). Nature managers should therefore try to restore altered ecosystem properties to their natural (incl. hydrological!) conditions, in which fens become again self-sustaining, and limit 'remedial mowing' to the necessary minimum (Kozub et al. 2018).

Additionally, grazing with domesticated animals has been part of the traditional use of fens for millennia, both in lowland fens (Middleton et al. 2006) and in mountain areas (Maldonado Fonkén 2014), and has had a significant influence on the historical development of peatland habitats (Thom et al. 2019). In Tibet, grazing with yaks has even changed the hydrogenetic character of many peatlands, making them more susceptible to overgrazing and erosion (Zhang et al. 2016). Whereas grazing promotes structural diversity, it may also lead to local over- and undergrazing (Middleton et al. 2006, McBride et al. 2011).

Taylor et al. (2018a, b, 2019, www.conservationevidence.com) provide detailed information on the effects (what works and what doesn't work) of 125 different actions ('interventions') for managing and restoring peatland biodiversity (flora and vegetation) worldwide (with a focus on Europe and North-America), however without discussing causal relationships.

Sphagnum

Sphagnum mosses are arguably the most important peat-forming plants worldwide (Clymo & Hayward 1982). Furthermore, only a handful of lawn and hummock *Sphagnum* species worldwide are able to build an acrotelm that can raise the surface of a peatland above the influence of groundwater to become a 'raised bog' landscape (Joosten 1993). *Sphagnum* has, however, severe difficulties to re-establish spontaneously both in natural (Campbell & Corson 2014), drained (Price et al. 2016) and rewetted peatlands (Thomassen et al. 2012).

A study of 71 rewetted peatlands in Germany revealed that after 30 years only a few hollow species (*Sphagnum cuspidatum* and *S. fallax*) had re-established, whereas lawn and hummock species were absent (Andersen et al. 2017).

The failing or retarded recolonization may be due to the rareness of diaspore sources (as in W.-Europe), but will mostly relate to properties inherent to the plant. The large pores and loose structure of *Sphagnum* cannot generate a strong capillary rise to the capitula (the 'heads' of the plant), where growth takes place (Gauthier et al. 2018).

In order for the capitula to remain humid, water levels should therefore not drop too deep under the capitula. Under natural conditions this is secured by the 'acrotelm conditions' of the surface layer, i.e. limited horizontal permeability combined with a high storitivity (Joosten 1993) and the gradual transition of older peat to younger biomass.

After long-term drainage or peat extraction the low storativity of the remaining peat easily leads to deep water levels in dry periods (Schouwenaars 1993). Restoring a constant high water level is then only possible by raising the water level substantially *over* the compacted peat surface. This, however, favours the growth of hollow species, which outcompete the slower growing hummock species (Robroek et al. 2009). It may take (many) decades before the former have accumulated sufficient peat to make the environment so drier that hummock species can win the competition (Joosten 1995, Van Duinen et al. 2011, Lindsay & Clough 2016).

Water availability in the capitula can furthermore be improved by limiting evapotranspiration, e.g. by providing some shelter against light and wind by herbs or trees, or by covering the (re-introduced) peatmoss with straw, as is done in the Canadian Moss Layer Transfer Technique (see below).

Various methods have been developed to inoculate *Sphagnum* species, including:

- collecting and spreading of *Sphagnum* fragments (the Moss Layer Transfer Technique MLTT, see box),
- collecting and planting whole *Sphagnum* clumps,
- spreading of *Sphagnum* grown using micropropagation techniques (in e.g. gel beads),
- planting *Sphagnum* grown into plugs or as hummock from micropropagated *Sphagnum*.

Thom et al. (2019) provide detailed information on these methods. Except for the MLTT, these approaches are still in early stages of development. In general the transplantation of larger volumes is more successful than spreading less and smaller fragments (Robroek et al. 2009).

The Moss Layer Transfer Technique developed by the Canadian Peatland Ecology Research Group (PERG) for the restoration of peatlands (bogs, poor fens and moderate-rich fens), especially after peat extraction, is based on active reintroduction of peatland plant species, especially peatmosses, combined with rewetting. The method has been used in over one hundred restoration projects in Canada as well as in many other countries. It allows to establish over 80% of the species present in the plant material collected from the donor site, shows a progressive decrease in atypical species as the moss carpet develops, and may allow a restored peatland again to capture and sequester carbon 15 years after restoration (Nugent et al. 2018, Hugron et al. 2020, Quinty et al. 2020). The first MLTT restoration guide was published in 1997; a second edition in 2003 (Quinty & Rochefort 2003). In 2019 and 2020, the chapter dealing with restoration was revised and republished in independent booklets dealing with Planning restoration projects, Site preparation and rewetting, Plant material collecting and donor site management, and Spreading of plant material, mulch and fertilizer.

Once established, *Sphagnum* cushions somewhat stabilise soil moisture variations, more so in larger cushions (Robroek et al. 2009, Price et al. 2016). A vital *Sphagnum* layer also immobilises large amounts of nutients and prevent nitrophilous vascular species from becoming dominant (Tomassen et al. 2012, Temmink et al. 2017). A nurse crop may help to stabilize the peat, prevent erosion and provide physical shelter to newly establishing mosses (Sliva & Pfadenhauer 1999, Groeneveld et al. 2007, Dinesen & Hahn 2019).

Re-establishing light grazing on raised bogs may reduce shrubs and scrub and favour *Sphagnum* (Thom et al. 2019).

Open water colonisation

Peatlands with a meso- and slightly eutrophic character may easily revegetate and become peat accumulating after deep inundation (Minke et al. 2016). In contrast, recolonisation of low-productive oligotrophic, acid and humic rich deep open water is hampered by wave action and by lack of light and carbon gases for submerged mosses when the water is deeper than 30 cm (Van Duinen et al. 2017). Options to address this problem are i) to raise the water levels gradually to allow tussock vegetation to grow up with the rising water level), ii) to provide a framework for plant colonization by introducing brash or slightly humified peat, and iii) to minimize wave action by compartimentalisation (Joosten 1992, Wheeler & Shaw 1995, Tomassen et al. 2003, 2004).

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In 2019 and 2020, Chapter 4 was revised and republished in independent booklets;

- Planning Restoration Projects (replace pp. 13 to 24 in the 2003 Guide)
- Site Preparation and Rewetting (replace pp. 25 to 35 and pp. 60 to 62)
- Plant Material Collecting and Donor Site Management (replace pp. 36 to 45)
- Spreading of Plant Material, Mulch and Fertilizer (replace pp. 46 to 59)

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Annex VI: Monitoring and adaptive management

It is neither possible nor desirable to provide a complete “blue-print” for the implementation of restoration plans. During implementation, lessons will be learned as to what works and what does not and these lessons should be incorporated in subsequent work and future planning. Planning and design should therefore integrate monitoring, assessment and adaptive management in a continuous process of “learning by doing” (Parish et al. 2019).

Many stakeholders are concerned about the external effects of peatland restoration and are apt to interpret simultaneous or consecutive phenomena as a causal effect of rewetting, be it the flooding of cellars or the nuisance of midges and mosquitos. Monitoring can effectively demonstrate the true effects of restoration measures. The inclusion of a monitoring programme as an integral part of any restoration plan provides a means of demonstrating to stakeholders that their concerns are taken seriously.

Objectives, performance standards, and protocols for monitoring and data assessment should be incorporated into restoration plans prior to the start of a project. The monitoring strategy should consider that the final goals of restoration may only be attained after a long (and unplannable) period (Bonnett et al. 2009). This may require the formulation of indicators for the appropriate trajectory of ecosystem development towards the intended goal. Joosten (1992), for example, proposed calling ‘bog restoration’ a success, not when an autonomously functioning bog landscape has re-established (this would take a very long time) but when a ‘permanent’ establishment has taken place of those key species and communities that are able to rebuild such a bog landscape under current climatic conditions (Wheeler & Shaw 1995).

Monitoring within the project period should mainly focus on the ‘input’ parameters, i.e. are the planned measures adequately implemented. With respect to peatland rewetting and adaptive management this will especially concern the execution and after-care of water control structures, leading to the following recommendations (Wheeler & Shaw 1995, Similä et al. 2014):

- Monitor the condition of all water control structures.
- Check dams and bunds regularly, particularly following heavy rain events. Check also for erosion channels around dams and for scouring of the ditch base caused by strong overflows.
- Correct any damage as soon as possible. In case measures are not urgent, they may be postponed to a period with better access to machinery (e.g. a dry summer).
- Check for shrinking and cracking of dams during dry weather and take action to prevent water loss due to preferential flow though these cracks.
- As rewetting progresses, it may be necessary to increase the height of dams and bunds periodically, if the adjacent peat swells.
- Maintenance of 'internal' bunds is less important than of 'external' bunds. Vegetation growth may help to bind the surface peat together, but tree growth may increase drying and cracking.
- Mowing of vegetation may be beneficial if bunds have to be used for access.

In addition to addressing the input parameters, it is necessary to monitor output parameters related to the targets. Indicators for the climate effect would be peat accumulation/loss and GHG fluxes, and their proxies high and stable water levels, vegetation, and absence of subsidence. For various other ecosystem services and biodiversity vegetation could be a good indicator.

Thom et al. (2019) present extensive information on **monitoring methods and techniques** for:

- general site conditions (using field assessment, satellite-, UAV- and fixed-point photography),

- topography (using levelling frame, plane tables, hand levels, quick-set and similar levels, tacheometric surveying, theodolites, Electronic Distance Measurers EDM and Geographic Positioning Systems GP-, aerial photogrammetry, LiDAR),
- hydrology: water levels (using ground wetness, dipwells, water level range gauges, capacitance probes, chemical tracing techniques, data loggers, multispectral remote sensing, SMAP satellite based soil moisture content radar, modelling), seepage / discharge (using V-notch weirs, tipping bucket flow gauges, piezometers), evapotranspiration (using lysimeters) and rainfall (collecting and recoding gauges),
- chemistry: pH, electrical conductivity EC, and redox potential (using manual devices) and various ions/elements/substances (using laboratory techniques),
- peat depth (using coring and Ground Penetrating Radar) and peat properties, including degree of decomposition, texture, fibre content, bulk density, water, ash, soil organic Matter(SOM) and carbon content,
- surface level changes (using peat anchors, accumulation plates, LiDAR, photogrammetry,
- peat erosion (using reference markers, erosion pattern mapping, high resolution satellite imagery, LIDAR and aerial photography derived Digital Elevation Models DEMs, sediment trapping),
- vegetation (using permanent or random area, point or line quadrats, field, aerial photography or satellite-based mapping),
- fauna (using breeding bird surveys, transect counts, lek counts, mist netting, malaise traps, pitfall traps, water traps, light traps, suction traps, aerial attractant traps, emergence traps, and direct counting techniques such as transect walking, netting, hand searching, use of quadrats).

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Annex VII: Evaluation

Closely, regularly and systematically observing and documenting changes in the project area are all important steps in order to evaluate

- whether the targets have been met and remain being met,
- whether the money was spent effectively and efficiently, and
- what can or could have been improved (lessons learned for the current and future projects).

The ultimate test of success of peatland restoration is, obviously, whether the desired objectives have been reached (Wheeler & Shaw 1995). This means that these objectives should have been formulated as concretely as possible (see chapter 4). Simply proclaiming an area as "restored" prohibits any meaningful evaluation.

> "Success is a nebulous part of the lexicon of restoration; target criteria can vary widely in both ambition and rationale, even among stakeholders within the same project. Ecological outcomes also differ from success related to economics, aesthetics, recreation, or education. Setting evaluation standards requires consensus among scientists, funding agencies and citizen groups." (González & Rochefort 2019)

However, the long-time that full recovery is likely to require necessitates the formulation of intermediate targets against which progress can be assessed and necessary management adjustments can be identified. In general, the most immediate response is hydrological, followed by biological changes and ultimately regeneration of peat growth.

Long-term monitoring

The eventual "success" of practical restoration is hardly ever assessed in a systematic way. Degraded ecosystems usually recover slowly, whereas the costs of long-term monitoring and evaluation are often difficult to fund because schemes are too short (<5 years) and too restrictive (i.e. supporting implementation but not monitoring and evaluation (Andersen et al. 2017, Strobl 2019). As a result, most studies only cover a short time, whereas long-term studies are rare. This creates a risk of drawing premature conclusions on the efficiency of restoration (Klimkovska et al. 2014, Haapalehto et al. 2017). Furthermore, general long-term monitoring standards do not exist (Andersen et al. 2017, Artz et al 2018). Here remote sensing should be developed as a near real-time and cost-effective method for monitoring large-scale restoration projects (cf. Sirin et al. 2020).

Monitoring what?

The success of a restoration project is ultimately determined by whether the desired objectives have been achieved but in view of the long time-scales over which recovery is likely to take place, it is important that a series of intermediate targets be identified so that progress towards the goal can be assessed and adjustments to management operations can be made (Wheeler & Shaw 1995).

Monitoring of <u>water</u> levels and regular checks on the condition of water control structures allows the following questions to be answered:

- Are water levels consistently higher than previously?
- Have water levels stabilised and fluctuations been reduced sufficiently?
- Are water levels maintained at the required levels?
-

Note that assessment must be made with due regard to the actual and prevailing weather conditions.

Vegetation often concerns an operational tool (e.g. the establishment of ‘ecosystem engineers), a method of monitoring (bio-indication) and a goal of restoration (biodiversity conservation). The selection of species for monitoring could focus on all these aspects.

Certainly, the bio-indication aspect may be important to assess the short-term response on restoration activities and to indicate these activities have been appropriate for reaching the ultimate objectives. In this respect it is good to realise that it is easier to eradicate (unwanted) species than to regain target species (Haapalehto et al. 2017), so that ‘absence’ of species is also an important observation.

It is difficult and costly to monitor entire species assemblages so a few species groups have to be chosen. These could include:

- Ecosystem engineers, i.e. species that determine the strategic functioning of the ecosystem, e.g. specific *Sphagnum* species for bog habitats,
- Indicator species, i.e. species that reflect particular aspects of the habitat quality, e.g. water regime and quality, nutrient supply, disturbance, and may indicate specifc drivers of change (Strobl 2019),
- Characteristic species, i.e. species that are typical for (= consistently found in) a habitat, including flagship species which act as an ambassador, icon or symbol for the habitat,
- Dominant species, i.e. species that dominate communities.

Peat growth is more difficult to assesss, because increasing water retention within a formerly drained peat may cause a physical 'swelling' of the peat mass, which results in an increase in the relative height of the peat surface. The latter should not be interpreted as a sign of renewed peat accumulation.

Peat accumulation is a subtle process with large annual variation. Therefore it is – without direct long-term carbon flux studies (Nugent et al. 2018) or extensive palaeoecological analysis and dating (Joosten 1995, Mrotzek et al. 2020) – difficult to determine whether a peatland is actually peat accumulating. Indicators of peat formation are the prevalence of plants whose remains are also found in the uppermost peat, together with almost permanently waterlogged conditions (Joosten et al. 2017) and direct vegetation indication using specifically elaborated vegetation types (Couwenberg et al. 2011).

Restoration ecologists have traditionally focused on abiotic and vegetation-based properties as goals and as monitoring criteria, while animals have generally been less studied (birds being the exception). This is related to the assumption that if habitat quality and vegetation structure recover, the fauna will spontaneously follow. At the same time, vascular plants are easier to assess, show less seasonal variation, and integrate site conditions over long time periods.
However, it has been shown that insect communities do not recover to the same extent as plant communities. Animals are a significant part of ecosystem recovery, given their role as decomposers, herbivores and predators strongly affecting plant diversity and ecosystem functioning (Strobl 2019).

The Society of Ecological Restoration International (SER 2004) lists nine attributes for determining when ecological restoration has been accomplished. Gann et al. (2019) present a system of ‘stars’ to summarize recovery outcome. Bonnett et al. (2009) present an extensive review of techniques for monitoring the success of peatland restoration. Extensive information îs also found in McBride et al. (2011). Useful is also the Ramsar Handbook on Inventory, Assessment and Monitoring.[8]

Peatland ecosystems have often been developing for many thousands of years. In peatland restoration, however, time is often seen as a luxury because funding bodies demand evidence of value for money and proof of success within relatively short funding cycles.

This attitude highlights a marked imbalance between forest and peatland management: if a forest is being established, funding bodies tend to recognise that trees require decades to become established. Curiously, the same recognition is not afforded to peatland restoration although most peatlands typically have lifespans significantly longer than forests.

Some peatland responses can be surprisingly rapid and therefore fit within short funding timescales, but the majority are not and must be given time to stabilise and establish. This is a fundamental rule of peatland restoration management and evaluation – a rule that should be recognised by policy makers, academic researchers and practitioners alike. (modified after Lindsay et al. 2016).

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