RESTORATION OF UPLAND PEATS: A DISCUSSION DOCUMENT

Dr James Fenton, May 2023 ecology@fenton.scot

1. Introduction

It has been known for years that most of the natural terrestrial carbon in Britain is stored in the soil, with three quarters of it in Scottish peat (1). Because global warming is caused by the release of stored carbon into the air, primarily from fossil fuels, it is important to understand the role played by this soil carbon in either mitigating or contributing to climate change.

While active peat bogs take carbon out of the air, *i.e.* are carbon sinks, eroding peat does the opposite, releasing its stored carbon back into the air. Some peat bogs may be neither actively accumulating peat nor eroding and these are likely to be carbon neutral. Hence, in recent years, there has been increasing interest in peatlands, including: research into their role in carbon cycling; action to restore damaged peatlands; and action to prevent peatland erosion. Indeed, there are currently grant schemes available for restoration and erosion prevention.

At a landscape scale, calculating the carbon balance of peatlands is difficult, particularly when a given locality may contain areas of both actively growing and eroding peat. There is no quick and easy way to measure either the rate of carbon uptake or the rate of carbon release of a given peatland. A carbon calculator to assess the carbon balance of peat bogs is given in *An Illustrated Book of Peat* (2), but this presupposes knowledge of the current rates of growth and erosion, information which is normally lacking. In practice much action carried out for climate change mitigation reasons is, of necessity, based on simplistic assumptions of carbon balance. However, a crude assessment of the likely balance of a given peat is indicated by its vegetation and topography: see page 18.

This short paper discusses the appropriateness of peatland restoration and erosion prevention.

2. Different value systems

There are two environmental value systems involved in peatland restoration:

a. Nature conservation values

In the light of the continuing global loss of habitats, nature conservation is ultimately about conserving natural habitats and the associated ecological processes. The British Isles, and Scotland in particular, are a world centre for temperate raised bogs and blanket peat. Hence Scotland has an international responsibility to maintain both the extent and the naturalness of its peatland ecosystems.

b. Climate change mitigation values

In the light of anthropogenic global warming, society sees it imperative to mitigate the impacts of climate change. Terrestrial ecosystems have a role to play in this: any action which conserves or creates terrestrial carbon sinks, or which prevents release of stored terrestrial carbon, is seen as a priority.

These two value systems can be mutually incompatible because it not always the case that conserving natural processes and habitats will also be the best outcome for climate change mitigation, or *vice-versa*. For example, in some localities planting trees may increase the uptake of carbon, but if this is done in locations where trees would not naturally be present, then this could compromise the area's nature conservation value.

In relation to peatlands, the **conservation priority** will be to maintain/restore the natural processes, which will include allowing natural erosion to continue.

In contrast, **climate change mitigation priority** will be to prevent carbon release from eroding peat, *i.e*. to slow down or prevent erosion.

Hence, before action is taken at a given site, a decision has to be made as to which value system is the more important.

3. Types of peatland restoration

For details of the methods used to restore peatland see NatureScot's *PeatlandAction – Technical Compendium*:
https://www.nature.scot/doc/peatland-action-technical-compendium

a. Restoring obvious anthropogenic damage

- Removing planted trees
- Damming/infilling ditches (moor grips)
- Revegetating bare peat following intense fire/ mechanical damage (trampling, vehicles, construction)/air pollution
- Reprofiling vertical edges from peat cutting, vehicle damage, human trampling

b. Rewetting drying-out peatlands

(in addition to the above)

- Removal of self-seeded trees
- Bund building (raised bogs)
- Damming/infilling gullies

c. Reducing rates of erosion

(where no obvious anthropogenic damage)

- Damming/infilling gullies
- Revegetating bare peat
- Reprofiling & revegetating vertical edges
- Filling-in pools (not carried out in practice)

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(1) *Institute of Terrestrial Ecology report*, Melvyn Cannell et al., 1994

(2) *An Illustrated Book of Peat. The Life and Death of Bogs: A New Synthesis*, James Fenton, 2021.
https://www.nhbs.com/an-illustrated-book-of-peat-2-volume-set

4. Deciding the approach to take

Where damage to a peatland is obviously caused by human action (a. above), then there should be no contention: restoring such damaged bogs will be to the benefit of both conservation and climate mitigation. This also applies to the rewetting of lowland raised bogs (b. above) where agricultural and other activity has lowered the surrounding water table, even though the bog itself may not appear damaged; and also to the removal of self-seed and planted trees on such bogs.

However, action becomes more contentious when action is targeted at blanket peat, whether damming or infilling gullies, reprofiling vertical edges or revegetating bare peat. This is because it is likely that such features are characteristic of undamaged, natural peatlands: blanket peat cannot go on getting deeper for ever – the greater the depth and the older the peat, the greater the probability of erosion setting in. Page 7 shows examples of natural erosion.

It is commonly stated that "85% of Scotland's peat bogs are damaged", which, together with climate change mitigation, is used as justification for restorative action; but this justification depends on what is meant by the term 'damage', a term which normally implies human causation. It may well be true that there is at least some erosion of 85% of Scotland's peat bogs, but, if erosion is a natural feature, this is not the same as saying they are 'damaged.' Hence the phrase "85% of the peatlands are damaged" is misleading.

Therefore, the presence of at least some peat erosion on most peatlands is no justification in itself for remedial action. The different types of natural erosion are shown on pages 5 & 6. Additionally, because the determination of the carbon balance of a given area of peatland is difficult, if action is taken to reduce the rate of erosion, it needs to be reasonably certain that the action taken will in fact significantly change the carbon balance in favour of climate change mitigation.

Following the precautionary principle, unless there is strong evidence that restorative action will result in accelerated peat growth (carbon input) and/or significant decreased carbon output, then nature conservation should take priority. Even if it is reasonably certain that the action will shift the carbon balance in favour of climate change mitigation, this must be the balanced against the nature conservation need to maintain natural processes in peatland ecosystems. The situation is complicated by the fact that rewetting a peatland may result in increased methane output, a potent greenhouse gas, itself over short timescales. Is it worth reducing carbon dioxide from eroding peat if it results in greater methane output? These are difficult issues to resolve.

In the author's view, in the upland areas of Britain and Ireland, the world centre of blanket peat, the priority should be nature conservation, with action taken only if there is a strong probability of human-caused damage to the system. If a peatland is naturally eroding, then any action to modify this natural process is not 'restoration' but 'damage'.

5. Maximum peat depth

Many areas of upland blanket peat have vegetation which suggests that active peat growth has ceased. Blanket peat occurs because water is held by capillary action in the catotelm and this water does not drain out because capillary action is a stronger force than gravitational drainage: this is illustrated by the fact that water does not drain out of the vertical faces of peat cuttings.

However, there is a maximum height that water can rise under capillary action and this height depends on the pore size of the material in question. For example, the large pore size in sponges means that water cannot rise up very far (see page 8); in contrast, within peat, which has a small pore size between peat particles, water can rise up significantly higher. But there will be a limit to the depth of peat which still can hold water in the catotelm: after a certain depth has been reached, gravitational drainage will take over and permanently waterlogged new catotelm will no longer be able to form.

In other words, there is a maximum peat depth for blanket peat. This is a little researched topic, but the extent of blanket peat in 'poor condition' suggests that this limit has been reached over large tracts of our uplands. This means that rewetting such peatland will not result in the resumption of peat growth, but is likely instead to increase methane output. However, the maximum depth possible may vary, dependent on the morphology of the peat: highly decomposed peat, with a small pore size, may be able to reach a greater depth than other peatlands.

The above is speculation and research is urgently needed on this topic; as it stands, all the current efforts to restart peat growth in such situations could end up being a waste of time and money, and could discredit peatland restoration generally.

Where a peat bog is constrained by topography, or there is a permanent inflow of water, then there will be no theoretical limit to peat depth because in this case the water table is determined by the surrounding land and/or water flowing in. For example, at a site in Islay, a peat depth of 11 metres has recently been recorded.

THE LIFE AND DEATH OF AN OMBROTROPHIC BOG
over millennial timescales

Note: The pictures and diagrams in this section are taken from the Illustrated Book of Peat

It is fascinating that a single habitat type can exhibit such a wide range of different features

1. Peat-forming plants colonise
(here expanding left to right)

2. Smooth peatland expands to cover the whole landscape

3a. On gentle slopes pools are likely to form

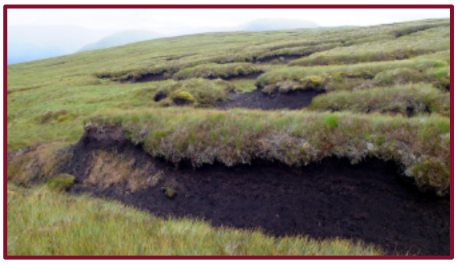
4a. Over time pools expand and coalesce

5a. Pools drain, resulting in peat hags

6a. Old peat erodes away, second cycle peat growth commences

3b. Peat continues to deepen on steeper slopes, with no pools

4b. The older the peat, the greater the probability of erosion setting in



5b. Erosion of first cycle peat continues

6b. Second cycle peat starts to grow in once eroded areas

Blanket peat goes through millennial cycles of growth and erosion (and possibly raised bogs as well on an even longer timescale)

All the stages of an ombrotrophic bog's life cycle are of equal importance in conservation terms

From a climate change mitigation perspective, the early stages of a bog life cycle will act as a carbon sink, while the later stages will act as a carbon source. However, in a given locality, all the different stages may be present, making it difficult to determine if the peatland as a whole is carbon positive or carbon negative. In practice, it is very difficult to assess the carbon balance of peatland at a landscape scale.

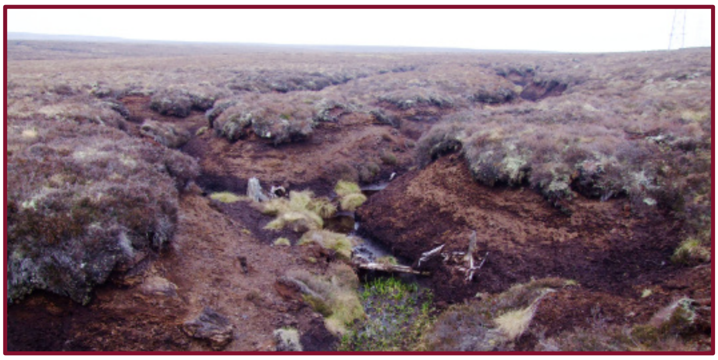
Because the probability of erosion setting-in increases with the age of the peat bog, early stage shallow peats have the greatest long-term potential as carbon sinks. However, it is often on such shallow peats that tree planting is taking place, which will result in both the oxidation of the soil carbon, and also prevent the area becoming a long-term carbon sink.

Early stage active peat growth. The vegetation is uniform and undiverse, dominated by common species: here heather *Calluna*, purple moor-grass *Molinia caerulea,* cotton grass *Eriophorum vaginatum* & deer grass *Tricophorum cespitosum*

Later stage pool development. Often the most biodiverse stage of a bog's life. In addition to the species listed on the left, here there is the locally rare brown beak sedge *Rhynchospora fusca* (yellow green in the water), white beak sedge *Rhynchospora alba* & bogbean *Menyanthes trifoliata*

Note that pools are erosion features, releasing carbon

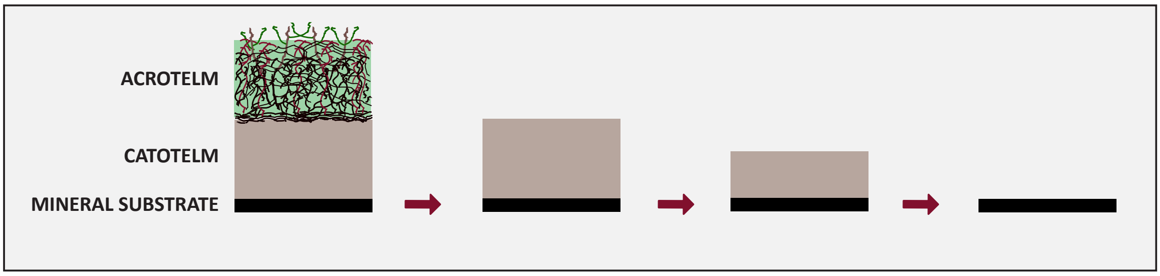
Drained pools. Pool systems can naturally drain, resulting in eroding peat.and an increased diversity of features



Late stage erosion. Vascular plant diversity has decreased although now with a greater diversity of lichens. Features include small hummocks and hollows on the surface, eroding faces and gullies. in time the eroded areas will most likely revegetate once the mineral soil is exposed

TYPES OF EROSION: CROSS SECTION

1. LOSS OF ACROTELM

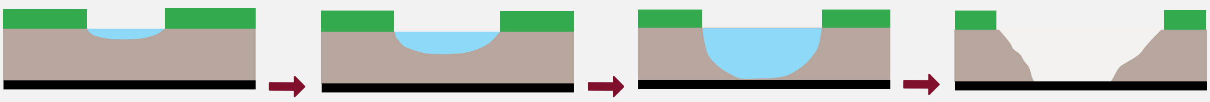


1a. Surface erosion

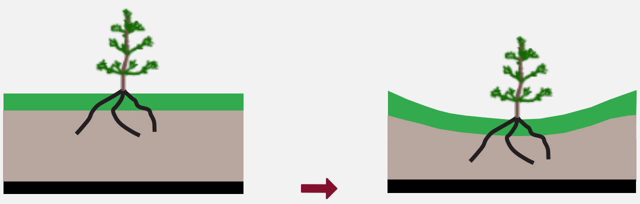
1b. Gully erosion

1c. Vertical edge cut-back

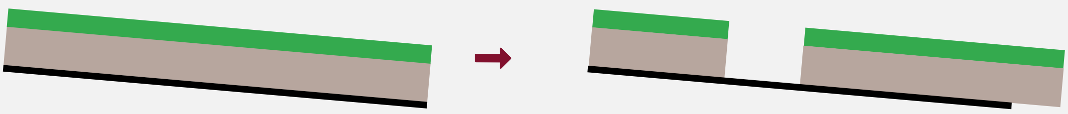
2. UNDERWATER



3. INTERNAL



4. CATASTROPHIC



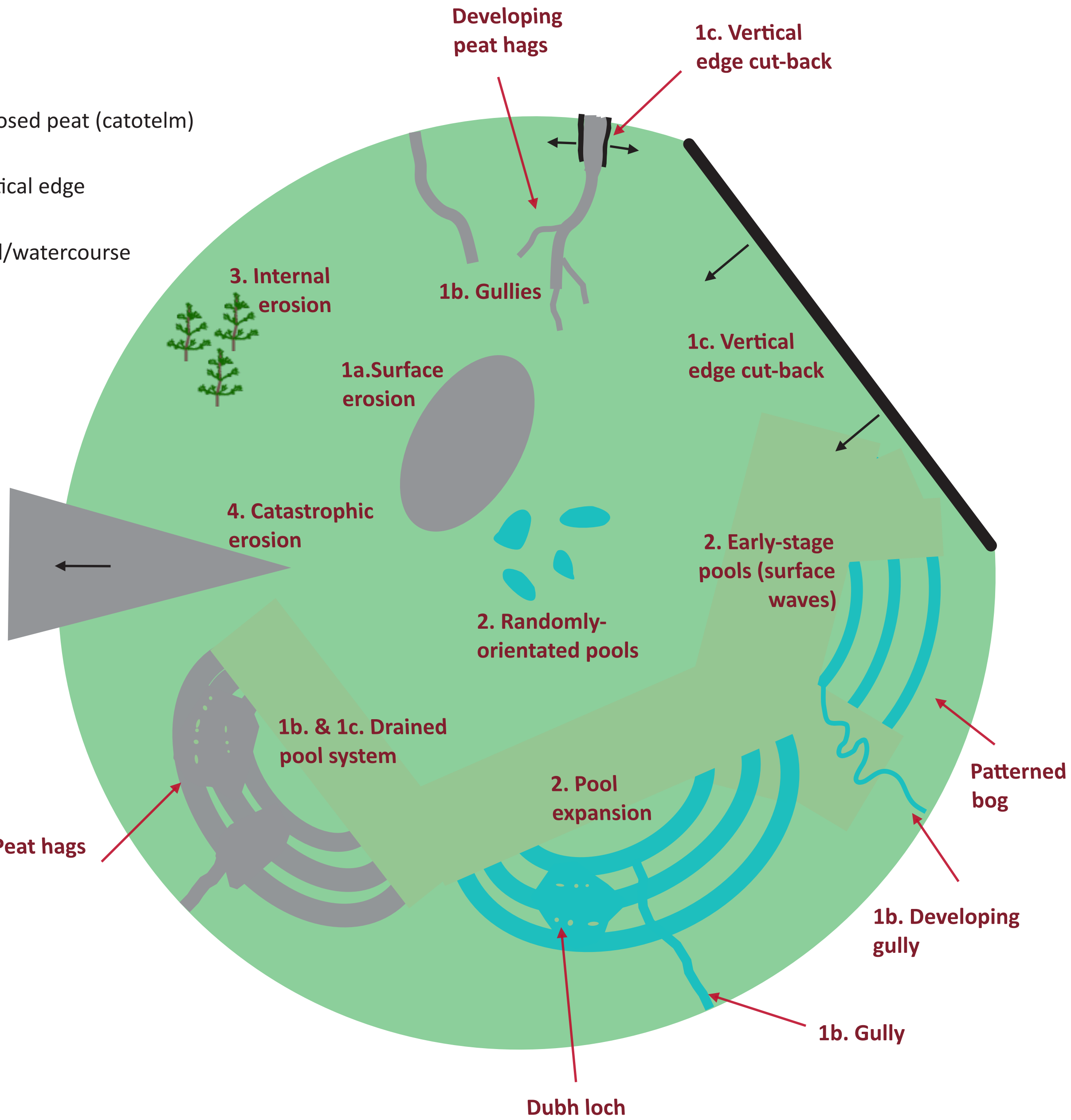
TYPES OF EROSION: PLAN VIEW

Stylised cross-section of a circular raised bog

Plan view of erosion types below

KEY

- Exposed peat (catotelm)
- Vertical edge
- Pool/watercourse



Surface erosion

Surface erosion can be natural, occurring even on peatlands unaffected by human influence and in the absence of fire.

These pictures show surface erosion on Antarctic moss peat banks in the South Orkney islands, locations without human impact. **Left**: Moe Island. **Righ**t: the surface of a several thousand year old moss peat bank on Signy Island.

Surface erosion caused by trampling damage, although post-dating the start of natural gully erosion and vertical edge cutback. (Glenshee, Perthshire)

Because the damage is human-caused, there is a strong case for revegetating the bare peat. But note that the site consists of old-growth peat with natural gully erosion, so that the trampling has merely speeded-up the natural erosion

Erosion of old growth blanket peat exacerbated by trampling from red deer. This is a natural process, with little justification for revegetating for nature conservation reasons. Whether it is worth doing for climate reasons is a moot point: it depends partly on how much new peat growth on previously eroded areas is taking place in the locality (Perthshire)

A location in Inverness-shire with eroding vertical edges (vertical edge cutback), but with also significant peat regrowth in previously eroded areas (second cycle peat growth)

This illustrates the natural millennial-scale peatland cycle characteristic of blanket peat

There is no justification for reprofiling the vertical edges in sites like this, both because it is interfering with natural processes and because it is probable that the new peat growth compensates for the carbon lost from the eroding vertical edges

Theoretical consideration of the cessation of peat growth in deep peat

Many higher altitude blanket peatlands have an appearance which suggests that peat growth has ceased. Features include a hummocky topography with small areas of bare peat and lichens common.

Blanket peat 2-3 m thick at 540 m altitude showing a discontinuous, tussocky acrotelm with bare peat and numerous lichens (Monadliath, Inverness-shire)

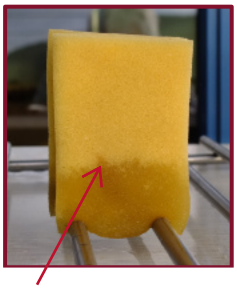
The reason why peat formation has ceased here is uncertain, but peat-forming species are now rare

One possibility is the peat-forming vascular plants are dying of old age

Another possibility is that the peat has become too deep for the perched water table to rise any higher; in other words, capillary action can no longer override gravitational drainage

Demonstration of capillary action: the maximum height the water can rise depends on the pore size.

There is a maximum depth blanket peat can reach



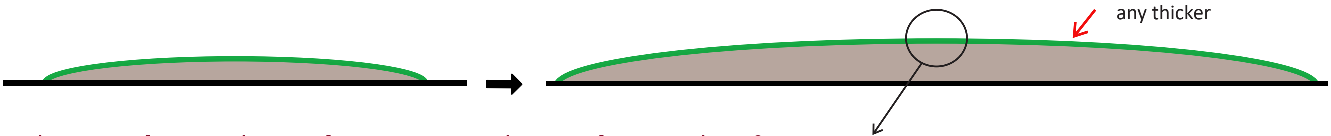
A wet sponge showing saturation at the bottom where capillary action is stronger than gravitational drainage: water is not draining out of the bottom

A compressed toilet roll fully saturated with green water: the water is held in place by capillary action and is not draining out. This illustrates what happens to water in the catotelm of a peat bog. It also demonstrates why moor grips do not dry out the peat

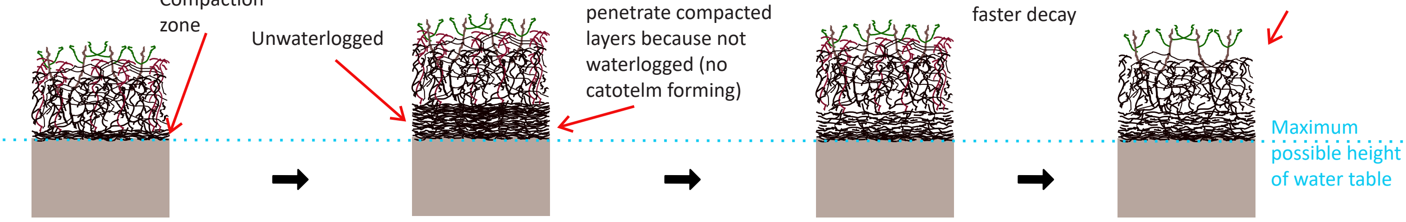
Because of its smaller pore size, water rises higher up the toilet roll than the sponge

A possible scenario for blanket peat: cessation of peat growth because maximum depth reached

Capillary action cannot raise water table any higher.



What happens if accumulation of peat ceases under peat-forming plants?
The diagrams below are an attempt to understand what might occur



1. Catotelm reaches maximum thickness for capillary action to continue

Compaction zone can no longer become permanently waterlogged

2a. Acrotelm growth and compaction continues as before

Lower layers of unwaterlogged compacted decayed plants become thicker, with decay continuing

2b. Over time plant roots can penetrate deeper, especially dwarf shrubs, drying out lower layers through transpiration

3. Lower layers decay faster because now drier

Catotelm remains stable because capillary action keeps it waterlogged

4. Plants characteristic of drier conditions now dominate

Acrotelm now equivalent to the humus of a podsol

Peat formation has ceased, but original catotelm remains

More research is needed on this topic. But if the perched water table reaches a maximum height, then 'rewetting' the peat will not result in a resumption of peat growth. Instead, it could result in increased methane output

Gully erosion – natural: restoration for conservation reasons not appropriate

Early stage of a natural gully forming on a raised bog (Claish Moss, Inverness-shire)

A late stage of natural gully erosion in old growth blanket peat, with the peat cut through to the mineral substrate at a depth of 2.5 m (Monadhliath, Inverness-shire)

Gully erosion – artificial: restoration for conservation appropriate

Ditches or 'moor grips' dug in peat do not dry out the peat, but can cause erosion through vertical edge cutback.

A new moor grip, dug in 2004 (Monadhliath, Inverness-shire)

Gully erosion caused by a moor grip (Northern Pennines)

Impact of drainage ditches

Two ancient parallel ditches cut through blanket peat at 500 m altitude in the Monadhliath Mountains, Scotland; they were cut to drain the ground between to create a dry footpath for deer stalking and could be of the order of 100 years old. The pale areas represent undisturbed peatland vegetation, and dark brown the drier areas where heather *Calluna* is dominant. It can be seen that the impact of the ditches on draining and drying the surrounding peat has been minimal because water does not drain out of the catotelm into the ditches, although there has been some vertical edge cut-back. If these ditches are filled in or dammed, this will not affect the hydrology of the peatland as a whole, *i.e.* will not result in rewetting, but will prevent erosion of the peat by preventing further vertical edge cut-back

A moor grip which has been dammed, thereby preventing erosion of the ditch. Note, though, that erosion (oxidation) of peat can occur underwater in pools, so that if open water remains present, the pools will themselves be erosion features (see page 13)

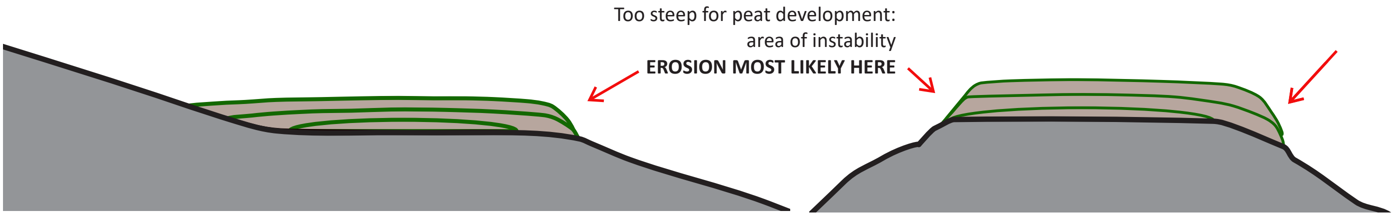
Vertical edge cutback – natural

Development of vertical edges is a natural feature of blanket peatlands.

Vertical edges of exposed peat on the downslope side of bogs are abundant on blanket peat.

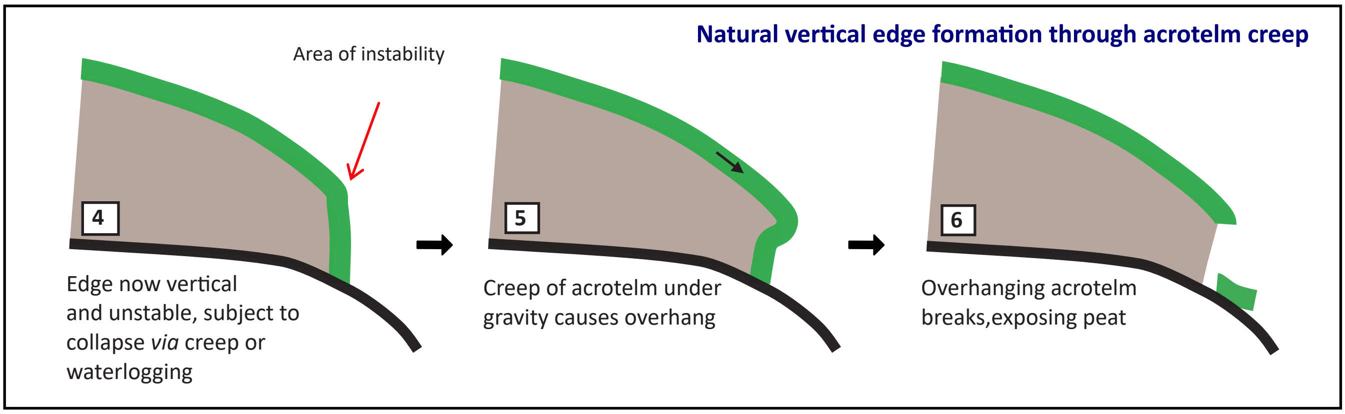
The vertical edges slowly retreat uphill as they erode. In some cases, such as the picture here there is recolonisation of the ground below the vertical face, so that the extent of exposed catotelm peat remains constant (Argyll)

Vertical edges occur in natural peatlands, here in Antarctica



Peat growing in an area of slope where the gradient lessens

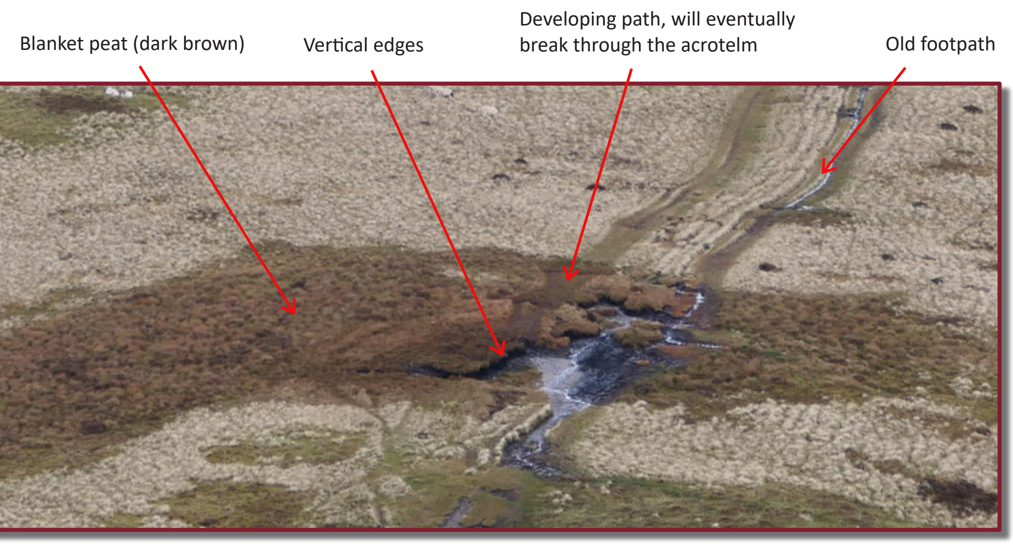
Peat on the top of a flat- or round-topped hill



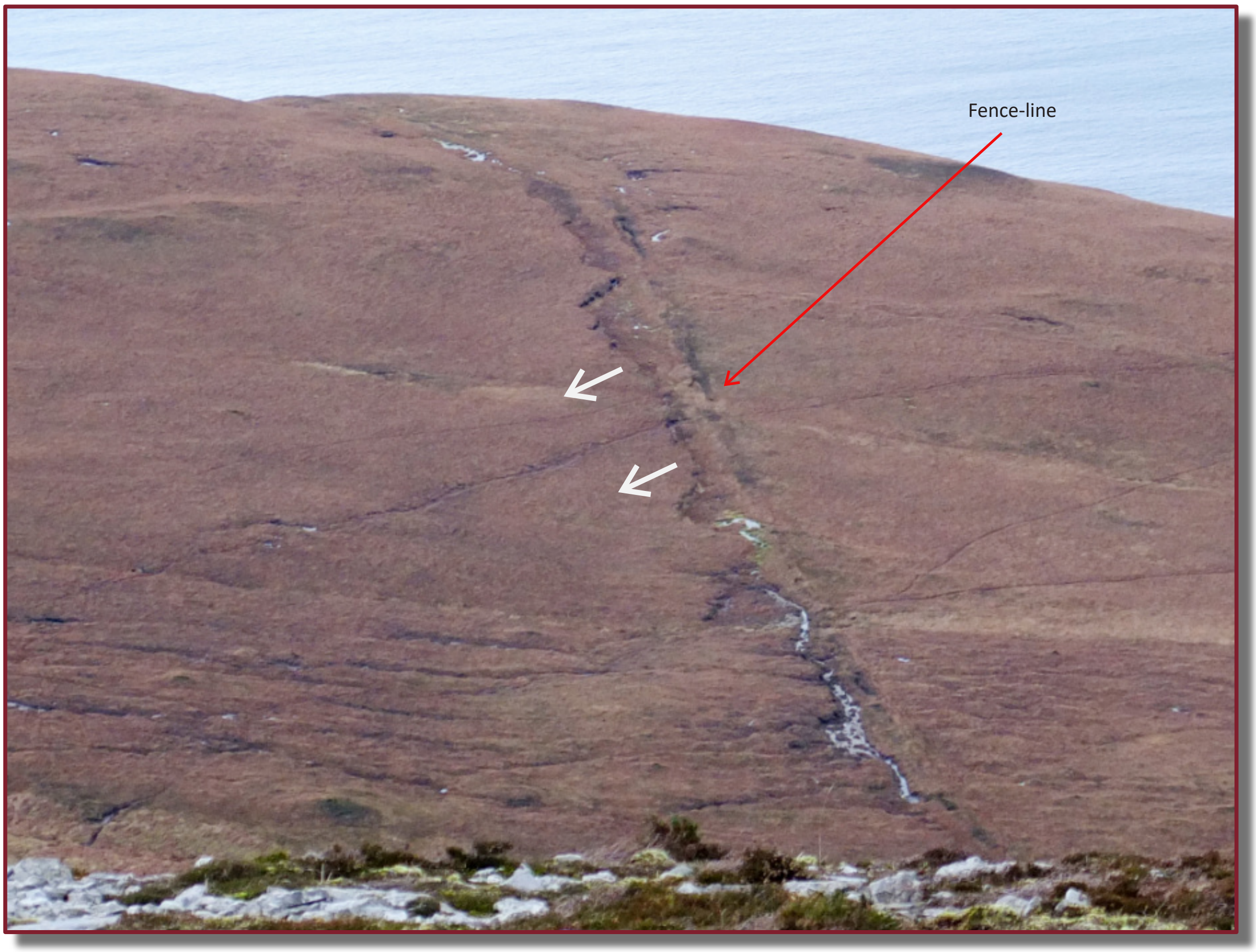
Vertical edges below a ridge of Coire Ceirsle Hill, Inverness-shire. The abundant vertical edges are of natural origin, and hence not in need of 'restoration'

Vertical edge cutback – human-caused

Where vertical edges have been caused by human action, then there is a strong case for their reprofiling.



A footpath through a developing area of blanket peat on a hill ridge has broken through the peat, creating a vertical edge. Mechanical damage can be caused by humans, domestic animals, wild animals and vehicles (Pentland Hills)



A vertical edge created by animals following a fence-line and causing trampling damage. The vertical edge so-created is cutting-back in the direction of the arrows (Islay)

Pools are erosion features

Pools on bogs expand over time, indicating that they are erosion features: oxidation of the peat occurs underwater.

A parallel pool system on a bog (a patterned bog) with the pools expanding and coalescing over time. This bog would have started off as smooth peat without pools. This indicates how pools are erosion features, with oxidation of the peat taking place underwater (Wester Ross)

A naturally-drained pool system. The ridges and hollows are still visible, resulting in a non-uniform surface and peat hags. Smooth, actively-growing peat without surface waves is visible on the left. This indicates another natural cause of peat erosion (Wester Ross)

Pools created on a raised bog through damming of a gully. The top picture here strongly suggests that peat oxidation will continue underwater, indicating that this restoration action may not be effective in reducing carbon output from the bog. There is a need for more quantification of such carbon flows before further such action is taken in the name of climate change mitigation (Argyll)

Cycles of growth & erosion

Vertical edge cut-back

Eroding (trampling)

Active peat growth

Peat regrowth

Early stage peat growth

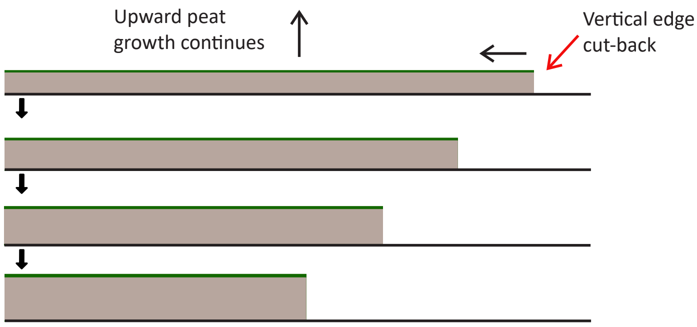
The island of old peat indicates that this peat bog has gone through one cycle of growth & erosion and is entering the second (Monadhliath)

Second generation peat growth, both deepening and advancing forwards

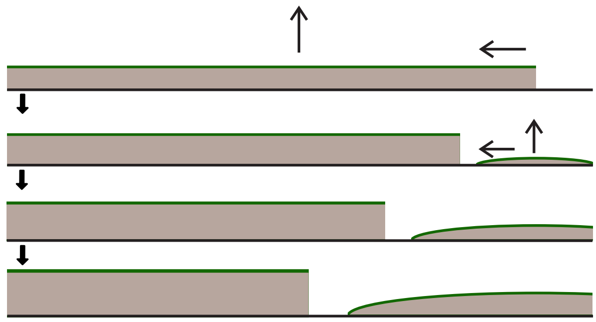
Old growth peat in the background with a vertical edge, which is likely to be cutting-back (eroding). However in the foreground there is active peat regrowth, which may counteract any peat lost through erosion – although more quantification of such carbon flows is needed; see page 17. In situations such as these, is it sensible to interfere with the natural processes of growth and erosion? (Wester Ross)

Long-term peat cycling: diagrammatic example of vertical edge cut-back

This diagram is designed to help assess whether, in areas where there is eroding peat, the overall carbon balance of the locality as a whole is positive or negative. Here modelled with the rate of vertical edge cut-back the same as the rate of the lateral growth of the peat.



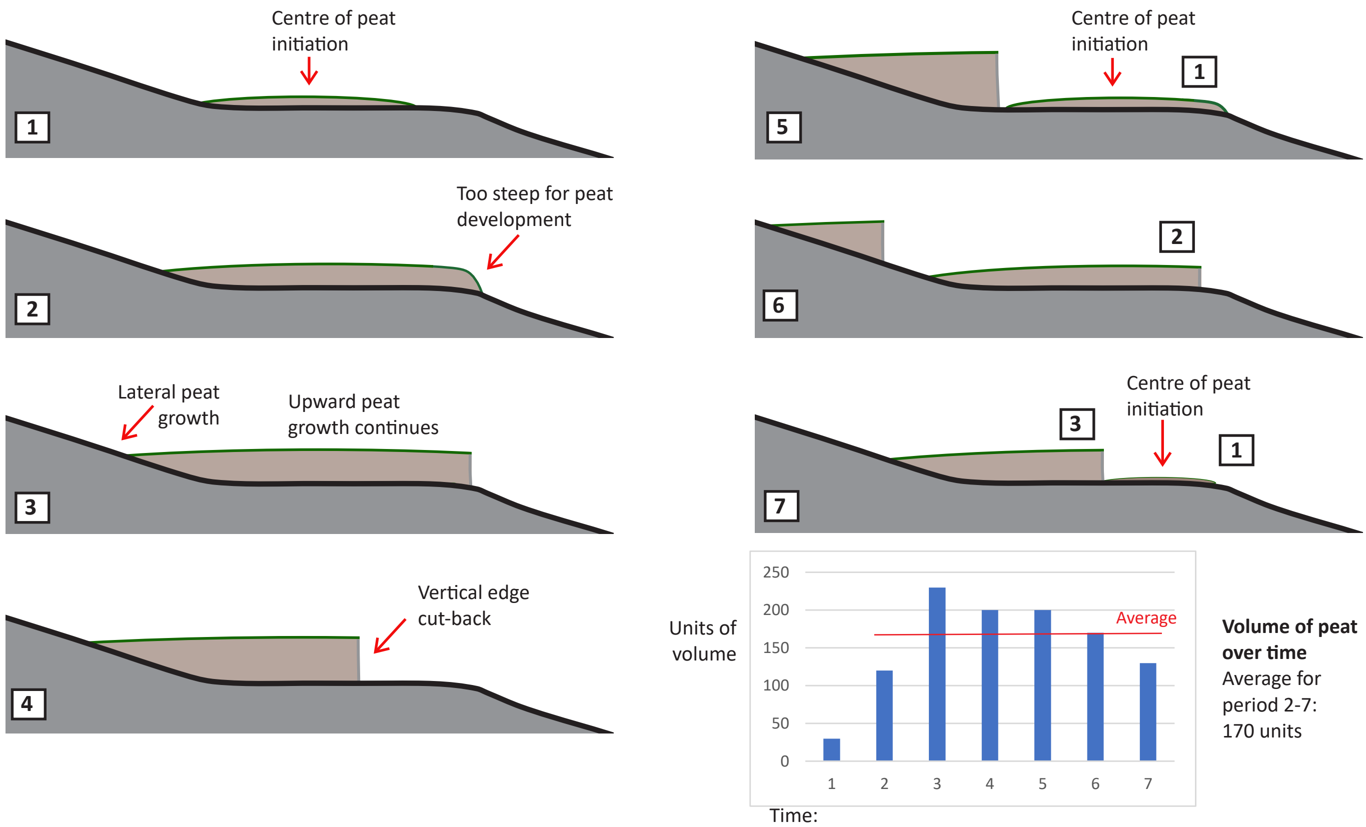
Vertical edge cut-back without revegetation:
Area of peat decreases over time



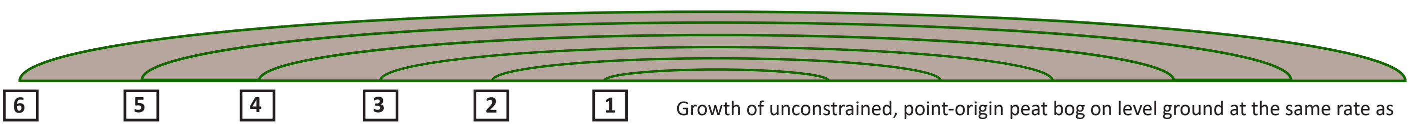
Vertical edge cut-back with revegetation:
Area of peat constant over time

Long-term peat cycling: diagrammatic example of peat bog growth and erosion on a hill slope

Here modelled with the rate of vertical edge cut-back the same as the rate of the lateral growth of the peat. This demonstrates the need to take a long-term view of peatland growth and erosion in relation to carbon balance.



Volume of peat over time
Average for period 2-7: 170 units

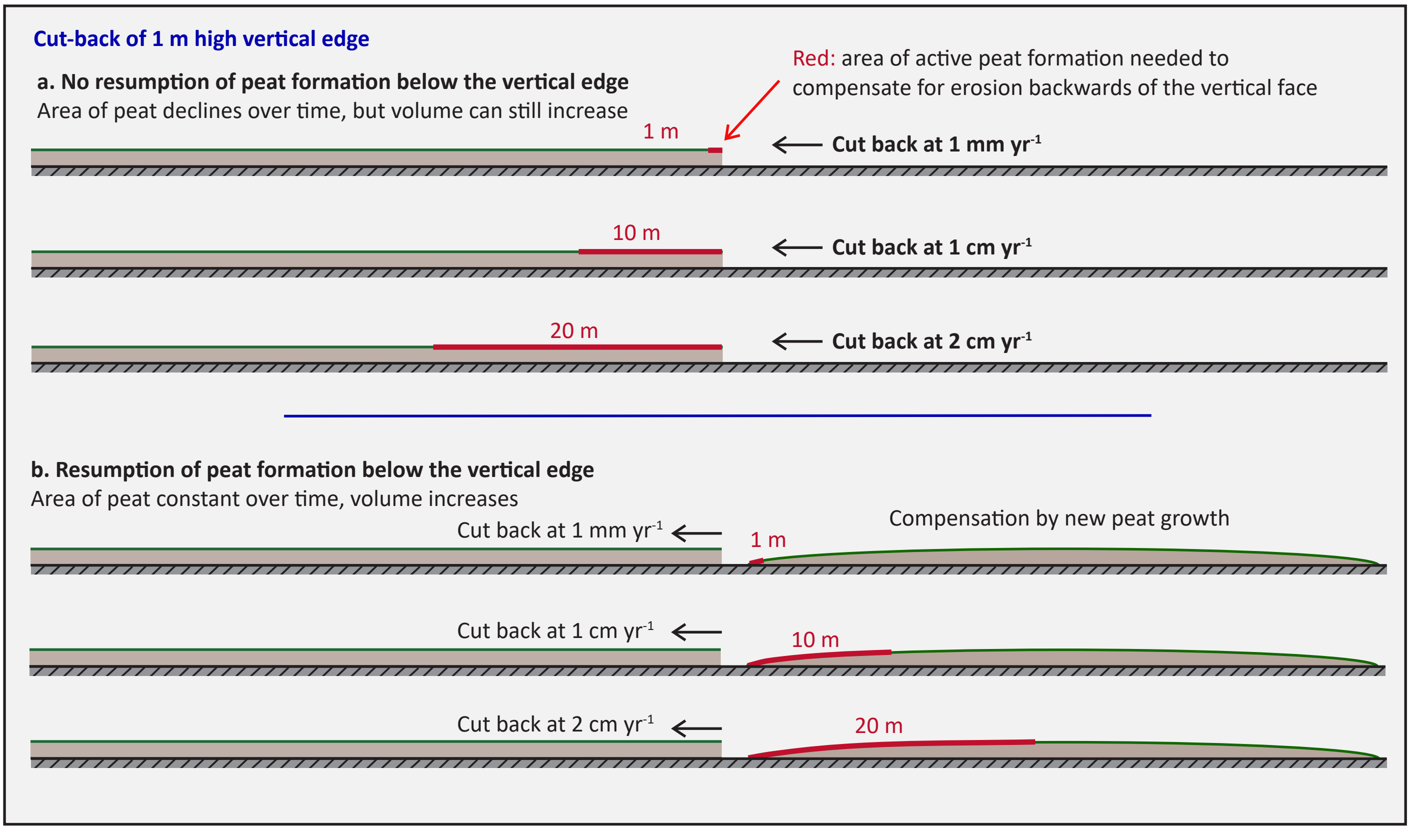


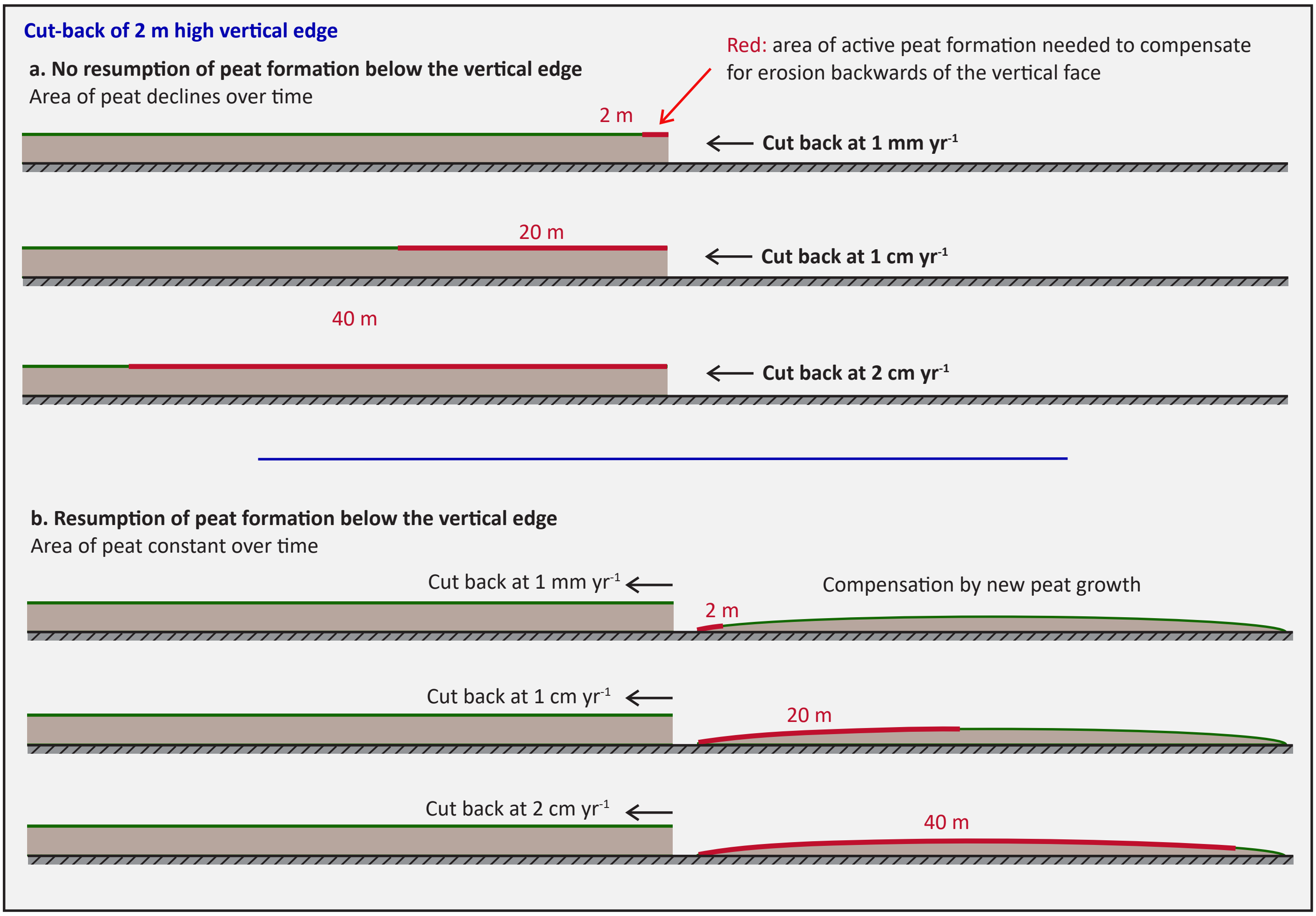
Regular time intervals

Growth of unconstrained, point-origin peat bog on level ground at the same rate as the bog illustrated on a hill slope and without erosion. Modelled with the rate of upward plant growth the same as the rate of lateral growth and a compaction ratio of 10:1 (*see Figure 1.27*)

Area of peat growth needed to compensate for peat lost through natural cut-back of a vertical edge

This is designed to assist in assessing the carbon balance of peatlands where eroding peat is present. Knowledge of both the rate of both peat erosion and active peat growth is needed in the locality as a whole: areas of active peat may be distant from the eroding areas. In practice this information is generally lacking owing to the difficulty of measuring them. Hence much restoration action on blanket peat is taking the place in the absence of the necessary quantification. In the diagrams below, the rate of upward peat growth is modelled at 1 mm yr^{-1}.





The feasibility of restoring old-growth upland blanket peat

An upland hollow with old-growth peat, indicated by the greyish colour. The site contains gullies and pools, and work has been undertaken to revegetate areas of bare peat (pale areas) and dam the gullies. There is one area of new, active peat growth visible (arrowed), but underwater erosion is likely to continue in the pools. Without a full quantification of the overall carbon balance of this locality, it is difficult to determine the long-term carbon impact of such action. It is also not certain if it is feasible to restart peat growth in such ancient, old-growth locations, rather than wait for the natural processes of erosion to continue and, eventually, for peat growth to naturally restart – albeit hundreds of years away. In practice, there has been little quantification of the rate of erosion on such sites (Cairngorms)

At this site, a helicopter has been used to carry materials up to the site and a digger used to reprofile the vertical edges. Initial calculations suggest that, to compensate for the fossil fuel used by the helicopter, then, for each hour's flying time of the helicopter, erosion will have to be prevented along a 100 m length of a vertical face 1-5 m thick which is eroding backwards at 1 cm/yr. Only if >100 m *per* hour's flying time is restored, will use of a helicopter result positive carbon balance for the first year, although benefits will accrue in subsequent years if erosion prevention has been successful. In practice, for most upland sites the rate of erosion is unknown

Similarly, to compensate for use of the digger, 25 m of a similar vertical face will need to be restored per day of use of the digger

Assessing the carbon balance of a given peatland

This table shows how a quick visual assessment can be made of the carbon balance of a given peatland. It should be applied to the whole peatland landscape, rather than focused on a particular site. Although based on a synthesis of the peatland processes discussed in this book, the table should be seen as a draft, subject to review based on future landscape-scale measurements of carbon balances. An additional method of assessing the balance is the carbon calculator in Appendix G of *An Illustrated Book of Peat*.

Scenario	Carbon balance	Example
Uniform, smooth surface of continuous vegetation without pools, hummocks, hollows or exposed peat	Positive	
Diverse short vegetation with short numerous lichens and often small unvegetated areas	Neutral, or possibly negative	
Diverse short vegetation with numerous lichens and often small unvegetated areas – with eroded locations	Negative	
Area of exposed catotelm less than area of vegetated active peat	Positive	
Area of exposed catotelm exceeds area of vegetated active peat	Negative	
Pools present, but surface area less than area of peat-forming vegetation	Assumed positive	
Pools present, but surface area greater than area of peat-forming vegetation	Assumed negative	
Colonising trees present	Could become negative in the long-term