Extracts from ...

Changing Carbon Stores in Peatlands Over Time.

A Level Geography Teacher Resource

[Welsh Peat Bogs within the Teifi Catchment.]

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February 2017

Amended August 2024

This document is an extract from a set of resources which were prepared for former colleagues teaching in Carmarthen, Ceredigion and Pembrokeshire schools. It was intended to introduce A level teachers to the important role peat mires/bogs play in carbon capture.

In its original form it included an introduction to peat bog formation, degradation and restoration and where possible, examples from within the Teifi catchment were used. Related issues such as carbon management and climate change impacts were appended for those colleagues who had not had the opportunity to study this topic first hand.

The original document summarised a wide range of sources, links to which appeared within the text and in the resource section at the end. The most important however, was the IUCN UK Committee, Peatland Programme's Briefing Notes.

If you wish to reproduce parts of this work that's fine, but please **ensure you credit the original authors/sources.**

Those wanting to access Teifi catchment information only, should focus on sections 6 to 10.

Acknowledgement - My background is in the Quaternary sciences and I am mainly interested in what bogs reveal about landscape evolution and past climates, rather than their fauna and flora. Consequently, I would anticipate that those of you with a deeper knowledge and understanding in ecosystems fauna and flora will "beef-up" any deficiencies.

Most of my Teifi catchment knowledge comes from fieldwork in West Wales over the past 35 years. Some in the company of Mike Walker *[Emeritus Professor of Quaternary Science in the University of Wales, Lampeter]* who along with, one of Mike's PhD students, Sean Buckley, introduced me to many of the secrets contained within the upland blanket bogs above the Teifi valley. Further, detailed information on the Tregaron raised bog system came courtesy of a Quaternary Research Association fieldwork meeting led by Keith Barber, Paul Hughes and Jenni Shultz of Southampton University. [2001]

The use of satellite and Lidar data in terms of landscape interpretation is an area of study, which I have applied successfully over the years and particularly in a long running Teifi estuary research programme. I would encourage colleagues to introduce their students to this geospatial resource, as much of the data is freely available and is easily manipulated on school IT systems.

TDW February 2017, [*Amended August 2024*]

Contents

Important Definitions

Acrotelm – the surface layer of an active mire where bog plants photosynthesise and grow. The plant supply zone.

Anoxic – severely depleted or without oxygen.

Archaic peat - Term used to describe degraded peatlands covered by agriculturally improved grassland or crops, or under the built environment.

Autotrophs - A organism capable of making nutritive organic molecules from inorganic sources via photosynthesis (involving light energy) or chemosynthesis (involving chemical energy)

Bare peat - Term used to describe areas of exposed peat.

Catotelm – relatively inert, permanently waterlogged peat forming zone.

Grips – artificial drains dug across upland peatlands for agricultural and game management.

Labile – chemically unstable

Macrofossils - with reference to peat this term applies to plant remains.

Microfossils - with reference to peat this term applies to pollen and invertebrates such as testate amoebae.

Microtopography - The patterned mosaic of pools, hummocks and lawns on the bog surface, created in part by the growth of the plants themselves.

Mire – is a peat-forming system

Moorland - A term used to describe unenclosed upland areas dominated by a range of semi-natural vegetation. **Not synonymous with peatlands**.

Oligotrophic - Low fertility, nutrient poor.

Ombrogenous - Derived from a water supply comprising only of precipitation.

Ombrotrophic - Where nutrient supply is derived from precipitation [rain, snow or mist], also referred to as rain-fed.

Peat - a relatively amorphous organic deposit consisting of semi-decomposed plant material mixed with varying amounts of inorganic, matter. In the case of UK peat bogs the mineral content may be as low as 2% by weight. Fen peat generally has higher mineral contents because it is waterlogged by mineral-enriched groundwater.

> **Limnic** peats form beneath the water table. [Lakes]
>
> **Telematic** peats form in the swamp zone between high and low water levels. [Swamps]
>
> **Terrestrial** peats accumulate at, or above the high water level. [Mires]

Recalcitrant - resistant to microbial attack, or chemical breakdown

Soil Organic Matter – [SOM] refers to all organic material present in the soil including the remains of plants and animals at varying stages of decomposition and the living plant and animal material on and below the soil surface.

Soil Organic Carbon – [SOC] refers to the amount of carbon stored in the soil. It is often expressed as a percentage by weight or as ***g C/kg*** soil. SOC can be expressed into SOM through a simple multiplication factor, usually taken as equal to 1.72 in mineral soils and closer to 1.92 in organic soils.

Soil profile - Vertical arrangement of soil layers forming the basis of all UK soil classification system.

Soil series - Group of soil profiles developed under similar conditions and similar parental material in UK soil classification. Also the smallest unit of soil mapping.

Soil association - A characteristic grouping of soil series, used to map larger areas and normally bearing the name of the dominant series.

Waterlogging - Permanent or temporary saturation of the soil from high precipitation and poor drainage, or where there is a more or less constant supply of ground water and/or surface runoff, in basins, floodplains or springs.

List of Abbreviations often used in literature discussing bogs/peat

µm	Micro (10-6) metre
C	Carbon
C:N	Carbon to Nitrogen ratio
CCW	Countryside Council for Wales now Natural Resource Wales [NRW]
DOC	Dissolved Organic Carbon
ER	Ecosystem Respiration
GHG	Greenhouse Gases
GJ	Giga [10^9]Joules
GPP	Gross Primary Productivity
Gt	Giga (10^9) Tons*
ha	Hectare
kyr	Thousand Years
Mg	Mega (10^6) Grams
MJ	Mega (10^6) Joules
Mt	Mega (10^6) Tons
N	Nitrogen
NECB	Net Ecosystem Carbon Budget
NEP	Net Ecosystem Productivity
ppmv	Parts per Million by Volume
POC	Particulate Organic Carbon
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
t	Tons
UV	Ultra Violet
WAG	Welsh Assembly Government
yr	Year

* Tons are usually metric tonnes in UK & European literature. US use tons [Short ton]

1 US Ton = 0.90718 Metric Tonnes

6. The Development of Raised Bogs in the Teifi Valley – Gors Goch, Tregaron

Location: 1 mile north of Tregaron on the Teifi flood plain. NGR: SN685622

Covering an area of 792ha, Tregaron bogs represent 11% of the near natural raised mire/bog resource of England and Wales. There are three active raised mire domes and two others in the northern and south western sectors of the system that have been destroyed by the extraction of fuel [ceased 1960s] and agricultural reclamation. Significant quantities of peat survive under some fringing fields.

1984 Landsat image – A Conifer Plantations, B Upland Blanket Bog, C Enhanced colour on steep slope exposed to sunlight, D Raised Bog, E Improved grazing, F Tregaron. Source TDW

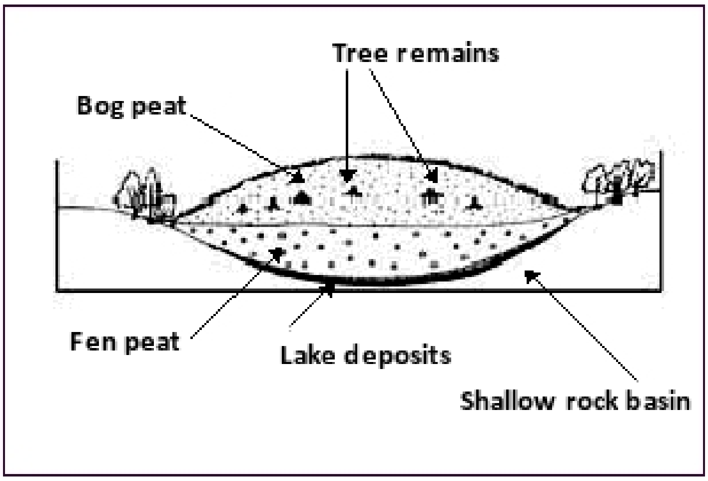


Diagram to show a section through a raised bog. Source: Prof' Mike Walker, UCW Lampeter

Raised bogs are so called because of the domed profile of the peat - highest towards the centre of the bog and gently sloping away towards the edges rather like an inverted saucer.

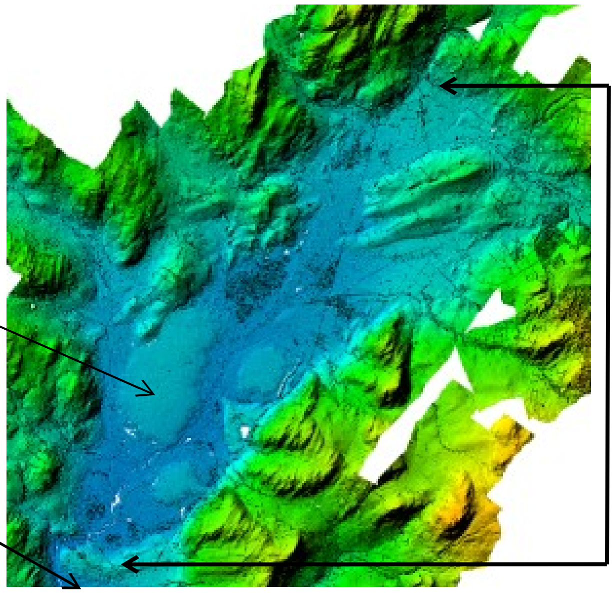
6.1 Raised bog formation in Mid Wales started at the end of the Younger Dryas[1] just over 11,000 years ago. The ice front had retreated northward in the main leaving large areas of ice to waste away in situ. At this time the evidence suggests that some areas within the Teifi valley were covered by small lakes formed from the melt water. These lakes tended to form where glacial ridges, such as moraines and kames, impeded free drainage and trapped the water. Just north of Tregaron it appears that two glacial features combined to provide a suitable location for such a lake to form :-

1. Late Pleistocene ice gouged out a shallow 10m trough in the valley bedrock.
2. A depositional feature, deposited as the ice thawed, formed a barrier across the valley.

1This was a return to glacial conditions after the last glacial maximum, which temporarily reversed the gradual climatic warming

Tregaron, Cors Caron Raised Bog System

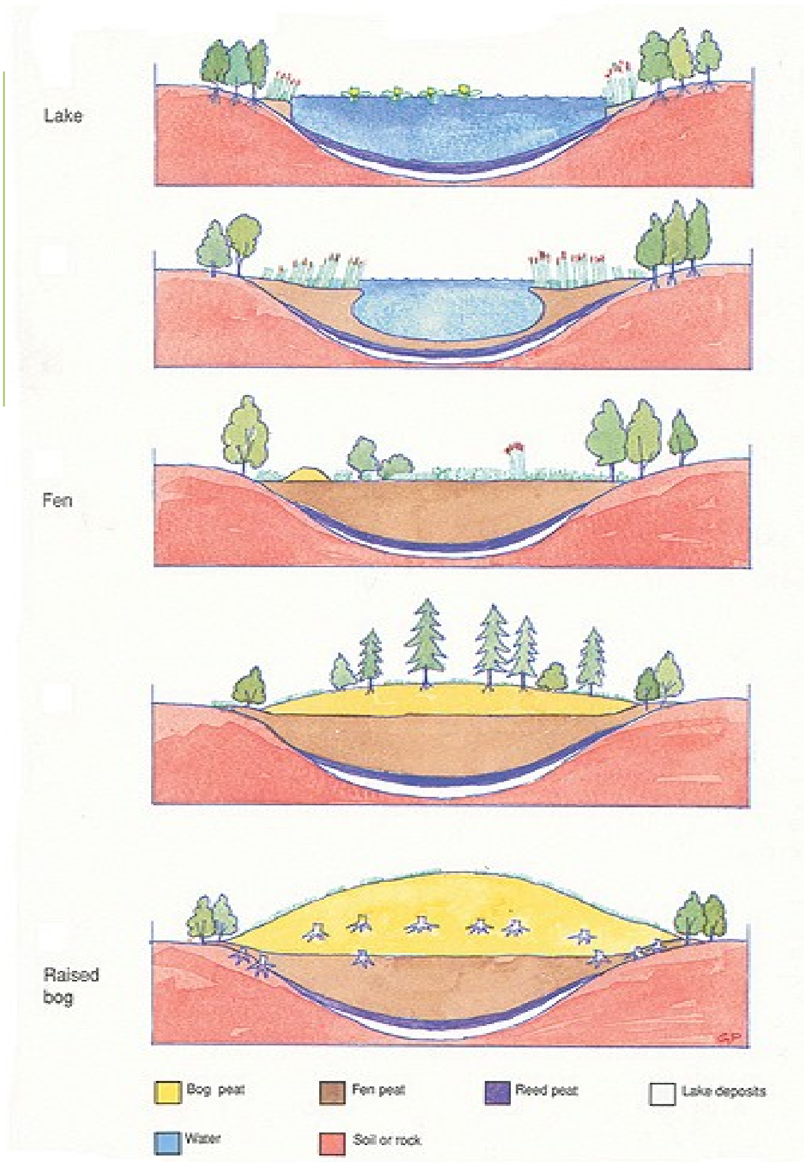
Barrier



Ice gouged basin trending NE/SW and illustrated by bluer shades. Green represents the higher terrain of the basin margins.

2002, 2m DSM Lidar Data of the Tregaron Raised Bog System – Source TDW

Consequently, in the depression to the north of the barrier a meltwater lake formed. Given enough time, lakes silt up and where the right climatic conditions exist, mires form. In this case Cors Goch Glan Teifi was produced, one of only two large remnants of active raised bog left in Wales.



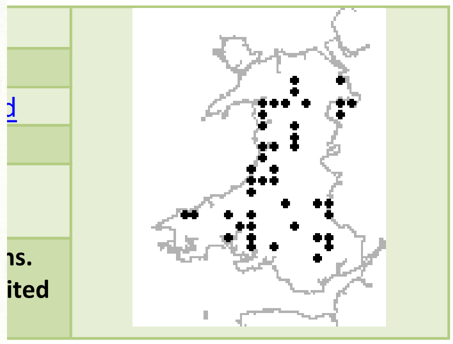


Table 2. Welsh Raised Bog Systems Source: JNCC – Joint Nature Conservation Council - a statutory adviser to UK Government and devolved administrations

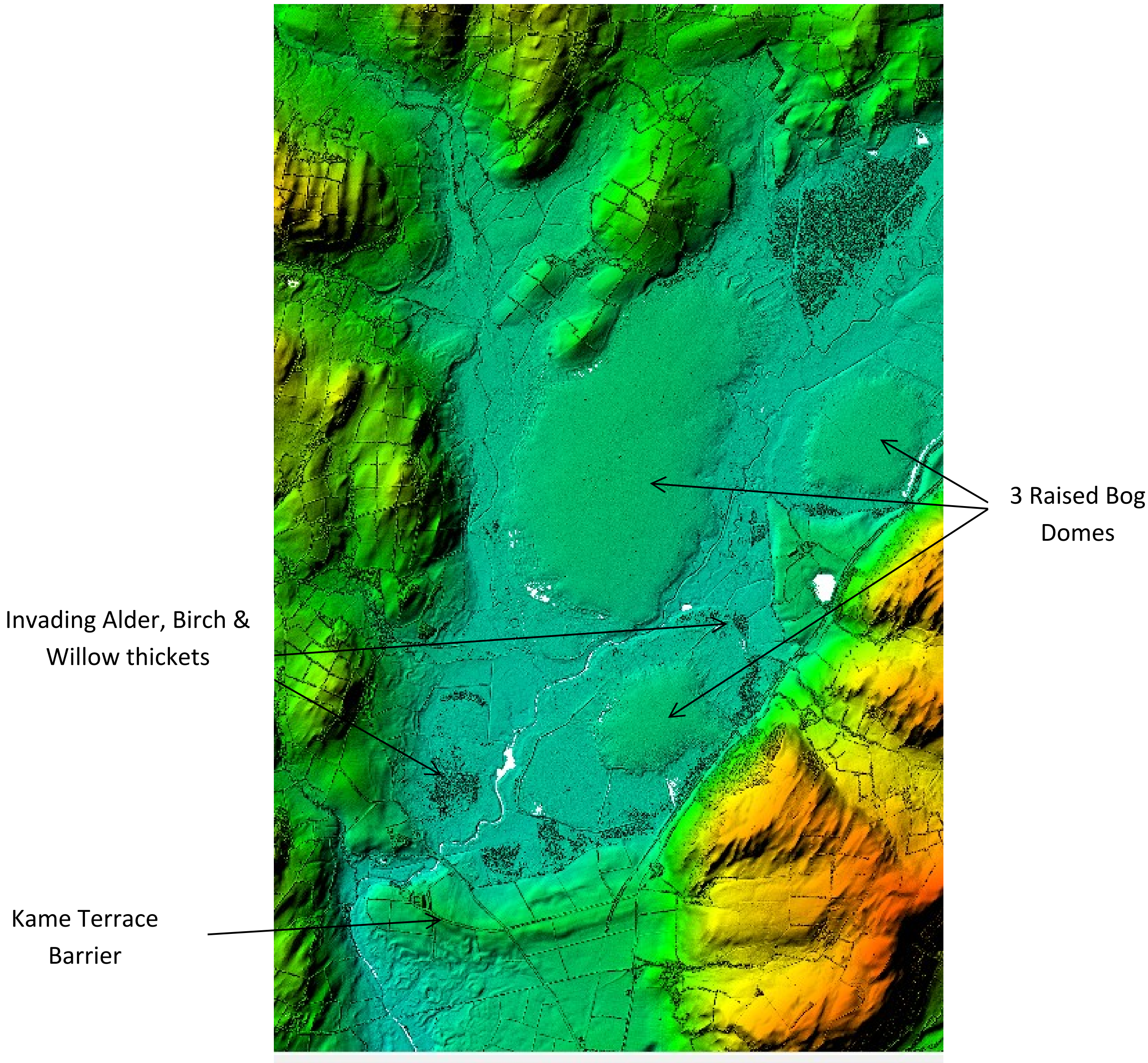
Raised bog formation diagram. Source: Irish Peatlands Conservation Fact Sheet from an original diagram by Cross 1990.

The lake, out of which the bog formed was originally fed by mineral-rich waters and supported floating plant communities. These sometimes produced thin peat layers just above the lake bed.

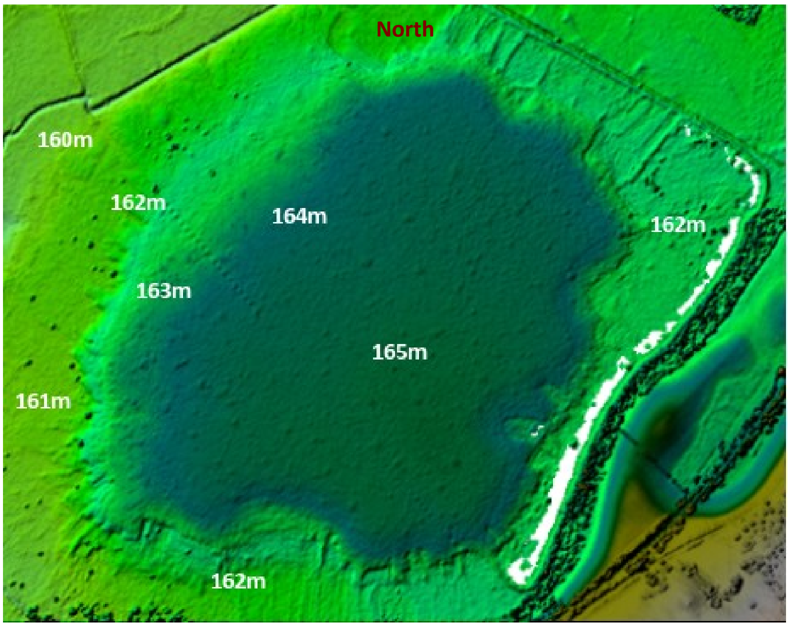
The lake edges were dominated by tall reed and sedge beds. As these plants died, their remains fell into the water and were only partly decomposed. They collected as peat on the lake bed. With time, this process formed a thick layer of reed peat that rose towards the water surface. As the peat surface approached the upper water level, sedges expanded, and their remains added to the accumulating peat.

Eventually, the peat layer in these shallow lakes became so thick that the roots of plants growing on the surface were no longer in contact with the mineral and nutrient rich waters below. When this happened the only source of minerals and nutrients for the plants came from rainwater. This is a very poor source of the essential minerals needed for plant growth. As a result, plants invaded that were able to grow in the mineral-poor habitats on the surface of the peat.

The best indicator of the changing conditions was the invasion of Sphagnum moss. This moss became common and made the ground even more acidic. Plants typical of raised bogs, such as heather [*Erica tetralix*], cotton grass, sundews, sedge and bog rosemary invaded. Where the water table has been lowered, such as the tops of the Sphagnum hummocks, heather, rush and deer grass predominates, producing today's familiar habitat. In some of the peripheral areas adjacent to the raised bog and alongside pools of open water, alder, birch and willow have invaded. Purple moor-grass is particularly prominent on the more modified bog margins. This variation in the vegetation cover stands out well on the satellite and Lidar images.

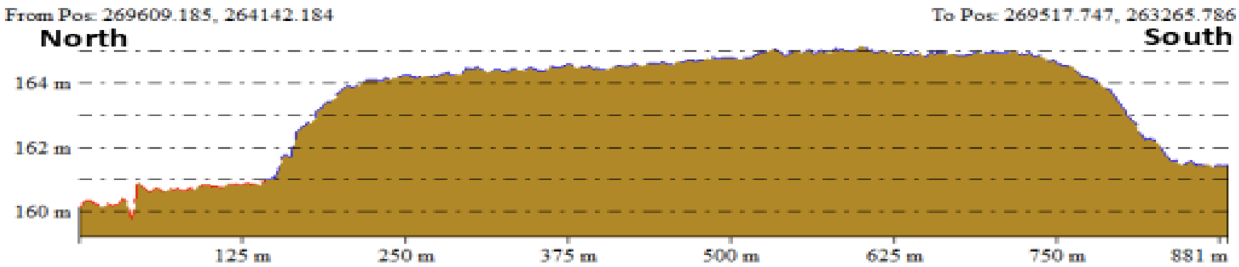


2002, 2m DSM Lidar Data of the Tregaron Raised Bog System - TDW



2015, 1m Lidar Data of part of the East Bog, Tregaron Raised Bog System – TDW

The mottled nature of this image reflects the bog's hummocky surface. The colour shader applied to this Lidar image is based upon elevation and reveals the domed nature of the raised bog. Heights in metres above ODN.



North to south cross-section through the East Bog . The raised bog stands around 5m above the surrounding area and is a little over 650m in length. Some of the larger surface hummocks are up to 11m across.

The Sphagnum is important as it acts like a sponge, drawing up water and keeping the surface of the bog wet and waterlogged, even in the dry periods. So, although the bog continues to grow upwards, away from the water table, the moss ensures that the water table rises in tandem with the rising peat level.

In some traditional ecosystem models, the succession from open water to mire and bog is known as a hydrosere. The raised bog was seen as its final stage. This is not a view that the evidence supports however as there appears to be repeated wetting and drying of the area.

7. Subdivisions of the Holocene Epoch

7.1 The Peat Archive – The plant and pollen species preserved in the peat reveal how the climate and environment of the area has changed over time. During Cors Caron's long history of bog growth, there have been changes in the overall climate of Wales for example. About 7,300 years ago the annual rainfall decreased. This caused bog surfaces to dry, and allowed the invasion and establishment of Eriophorum vaginatum [cotton grass] on the surface of the bog. The presence of charcoal indicates wild fire events. Wetter phases punctuated the record until about 4,500 years BP. At this point the surface of the bog dried out again, this time significantly and a pine wood developed. This woodland persisted for some 500 years, until the climate reverted to a wetter form. Rapid bog growth recommenced as the surface became waterlogged, and the trees died. There is some debate as to the role of early settlers in this process clearing the woodland to improve hunting and grazing.

The Tregaron bog system provides the principle pollen reference source for West and South Wales and helps in our understanding of climate change and the landscape and ecosystems' response.

Subdivisions of the Holocene Epoch					
Period	**Epoch**	**Stage**	**Age BP**	**Climate**	**Evidence**
Quaternary	**Holocene**	**Subatlanti c**	2,500 to present	Climatic deterioration – cool & wet	Poorly humified Sphagnum peat
		Subboreal	5,000 to 2,500	Climatic optimum – warm & dry	Pine stumps in humified peat
		Atlantic	7,000 to 5,000	Climatic optimum – warm & wet	Poorly humified Sphagnum peat
		Boreal	9,500 to 7,000	Rapid amelioration – warm & dry	Pine stumps in humified peat
		Preboreal	11,500 to 9,500	Rapid amelioration - subarctic	Macrofossils of subarctic plants in peat
		Younger Dryas	12,800 to 11,500	Near return to glacial conditions. - drastic cooling and drought	Organic component in lake sediments disappears
	Pleistocene	**Bolling-Allerod**	14,700 to 12,700	Rapid amelioration - warm and moist climate. Transition from Pleistocene to Holocene	Temperate forests expanded, followed by the expansion of evergreen and deciduous forests – Pollen & macrofossils

Figure. Subdivisions of the Holocene. Source:

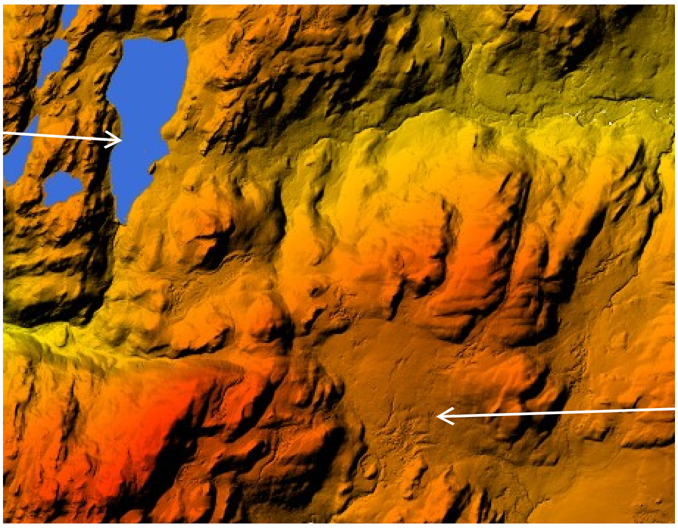
8. The Development of Blanket Bog on the Watershed of the Upper Teifi Valley – Bryniau Pica

Location: On the watershed between the Teifi Pools and Claerwen Reservoir. NGR: SN802659

1997, Aerial photograph of the Teifi Pools/Claerwen watershed looking north. The eroded surface of Bryniau Pica [part] appears in the lower right hand corner.

Altitude: ~455m Peat depth: 4.6m

In the Elenydd/Cambrian Mountains there are distinct rocky outcrops that trend NNE by SSW. They reflect the highly folded local bedding of the underlying Silurian sediments. However, in places these features are masked by the overlying peatlands.



2002, 2m DSM Lidar Data of the Bryniau Pica Upland Blanket Bog System - TDW

Blanket bogs are typical of the upland areas of Wales, and their shape reflects the contours of the landscape, consequently overlaying them like a blanket! They are ombrotrophic, water-shedding features and are therefore significant sources of water for the water industry. [70% per cent of the UK's drinking water comes from the peat uplands.]

Welsh Blanket Bog Systems JNCC		
Sites of Primary Importance	**Qualifying feature only**	
Berwyn a Mynyddoedd de Clwyd/ Berwyn and South Clwyd Mountains	Cadair Idris	
Elenydd **– Bryniau Pica**	Eryri/ Snowdonia	
Migneint-Arenig-Dduallt	Gweunydd Blaencleddau	
	Rhinog	
Follow these links for brief descriptions. Berwyn or Migneint good alternatives to Bryniau Pica.	Usk Bat Sites/ Safleoedd Ystlumod Wysg	

Table 3. Welsh Blanket Bog Systems Source: JNCC – Joint Nature Conservation Council

Bryniau Pica is a small part of the Elenydd which comprises the largest extent of blanket bog within the uplands of central Wales. Areas of good quality mire are fragmented. In between, large areas have been modified by human activity leaving a vegetation cover dominated by grasses [purple moor-grass *Molinia caerulea], some* dwarf shrubs and widespread *Sphagnum* mosses. Where the habitat is healthy, the wetter mires are comprised of *Erica tetralix* , *Sphagnum papillosum* with locally abundant bog-rosemary. 'Drier' mires see a switch to the heather *Calluna vulgaris* and hare's-tail cotton grass. Areas of pool, hummock and lawn pattern the surface locally, but elsewhere the mire surface is heavily eroded.

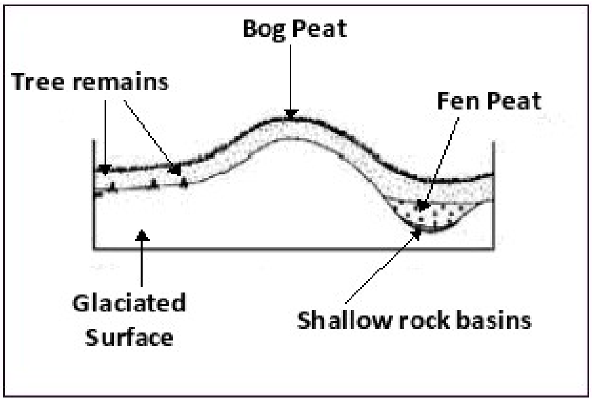


Diagram to show a section through a blanket bog. Source: Prof' Mike Walker, UCW Lampeter

8.1 Blanket bog formation on the glaciated plateau around Teifi Pools also started at the end of the Younger Dryas, however there was a time lag due to the elevation of some 500 plus years, putting the age of the base deposits at about 10,500 years BP. Initially, peat formation was confined to shallow lakes and wet hollows, which had formed in depressions gouged out by the ice. An infilling sequence from open water to telmatic peats[2] and terrestrial peats has been recorded in these areas. Later, peat spread out to form a blanket covering a huge area. It is thought that the initial spread may have taken place as early as

2 Telematic peats, sometimes termed reed peats are developed in very shallow water and consist mainly of reeds.

7,000 years ago, although many areas were not engulfed until 4,000 years ago when the climate became wetter.

Heavy rainfall caused minerals such as iron to be leached from the surface layers of the soil. These were deposited lower down where they formed an impermeable layer known as an iron pan. Water cannot move down through such a layer and the soil surface became waterlogged as a result. Under these conditions the accumulation and spread of peat was made possible.

8.2 What can the Bryniau Pica peat tell us? – It is not all about sphagnum moss accumulation.

At Bryniau Pica there is a 4.6m peat deposit which has accumulated over the last 9,500 years. As you walk across the present eroded surface of the peat you can see the well preserved remains of birch trees that grew in this area some 4,000 years ago! Extract some core data and you find evidence for climatic change as the region swung between wetter and drier conditions.

At some levels it is clear from the wood fragments preserved in the peat that these now open uplands were once extensively covered with oak, hazel and elm. By going deeper, birch and sedge remains point to a wet mire type of environment.

Colour change represents a change in vegetation as the area experienced dryer conditions [lighter brown]. Wet conditions darker colouring.
Not clear in this image but dark black lines are charcoal from dry times when fires occurred. Some of which may reflect early human activities of using fire to clear the area.

Core profile from Bryniau Pica Source: Walker & Wright

Apart from macro-plant fragments –like root, leaf, branch, seed, nuts etc, microfossils also give information.

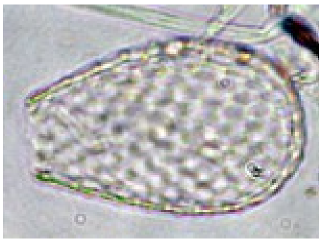
Microgrphs of birch and oak pollen grains extracted from a peat core.

Microscopic animals also reveal changing conditions and are particularly helpful as climate change indicators over the last 10,000 years. Testate amoebae [Protozoa: Rhizopoda] are unicellular shelled animals which are common in the surface pools of most peat bogs. The tests/shells are also preserved in peat layers as microfossils.

They are sensitive to changes in the hydrological conditions of the peat bogs and good indicators of the depth of the water table. Where a peat bog has a hydrological regime controlled by precipitation, the fossil testate amoebae preserved in a peat core sample can be used to explain past climatic conditions. However, problems can arise as some species are difficult to identify, others are poorly preserved, and we do not have enough current ecological information for some species.

Key markers include:-

A wet indicator - Amphitrema flavum



An indicator of intermediate conditions. - Euglypha tuberculata

Dry conditions. Assulina muscorum

8.3 Where have all the trees gone? - The peat record gives one or two clues to the answer. As the trees die away in the record, heathers and grasses start to appear. Evidence for this comes from the pollen record trapped within the peat deposits along with minute traces of charcoal. This indicates an opening up of the woodlands which is an unusual natural development. The fact that it first occurs some 8,500 BP and then again at around 7,500 BP might suggest that Mesolithic hunters were occasionally migrating into the area. Burning woodland increases variety in the vegetation cover as it recovers, which in turn expands the type of habitat and encourages a broader assortment of prey animals.

More extensive evidence shows up about 5,000 BP and at 3,000 BP which coincides with the expansion of early human settlements in West Wales in the Neolithic.

Why should they wish to clear these areas? – On this occasion it appears that the intention was to extend grazing grounds, possibly in response to a greater number of people sharing the available resources. It might also reflect the human response to climate change. At this point Wales's climate was becoming wetter and cooler. This would have an impact upon the yields produced from the arable farming practices of the time. Expanding the pastoral part of farming perhaps guaranteed a food resource.

8.4 How was such a clearance achieved? - Surely an early axe cannot be equated to the destructive power of a chainsaw? - Returning to the peat record the evidence takes an interesting turn. At the same time that the heathers and grasses start to appear and increase, so to, does the presence of charcoal. The area appears to be managed at this time by a variation of the "slash and burn" method of cultivation employed in tropical rainforests by indigenous people today. If, as it appears most likely, that it was done to extend grazing grounds, then the sheep or cattle moving across this area would ensure that the regeneration of the timber was severely inhibited. The repeated trace of charcoal through the upper part of the peat record suggests that the burning was carried out on a regular cycle. This is very similar to what happens on the Welsh uplands even now, when local hill farmers wish to encourage new growth in the heathers and grasses.

This early human interference has greatly influenced the manner in which this part of the Teifi's upland catchment now works. Being an area of high precipitation, it is a water shedding environment. It is fair to say that more water enters the system from an open upland than an equivalent area which is wooded. More water running off high ground leads to more erosion. Those peats that are now revealing so much about our early history are also disappearing downslope, washed away with the water.

This landscape demonstrates quite clearly the changes brought about by human demands. What the peat archive is revealing - is just how long we have been making those demands, - and how great the ecological and hydrological changes have been.

9. Degradation of Bogs

9.1 Introduction - After 5,500 years, little has changed! Human activities are still having a great impact on the health of Welsh bogs. The following are examples of typical impact sources associated with Welsh bogs:

- Atmospheric pollution
- Grazing [mainly sheep]
- Agricultural improvement schemes
- Drainage, Reseeding and fertiliser applications
- Over-planting with coniferous plantations
- Water storage reservoirs
- Road and rail links
- Quarry stone from uplands slopes
- Walkers, mountain bikers, off-road vehicles use the area recreationally.

When a bog is damaged it is usually the upper acrotelm that is lost. This exposes the catotelm peat to the effects of oxygen, sun, wind, frost and rain and so it begins to weather and erode. Carbon is released into the atmosphere and watercourses at an increasing rate as the exposed surface area increases. A peat bog in this state is termed a ***haplotelmic*** bog [a single-layered bog].

The impact of degradation can easily be misinterpreted leading to an underestimate of the damage. This is especially the case when the invading vegetation looks healthy as is often the case when heathland vegetation invades. Not being a wetland vegetation, heathland vegetation does not add fresh peat. Further, it causes more degradation of the peat through the aerating and drying action of its root systems. In this situation the hummock, pool and lawn topography first reduces in extent and is then lost. It is replaced by a tussock-dominated landscape. By the time the impact becomes more evident, the level of underlying damage has increased dramatically.

Young Molinia [Purple moor grass] –
Developing a healthy looking tussock dominated landscape.

In other instances, the surface can degrade into a full-blown erosion complex dominated by haggs and gullies. Inevitably, these physical changes produce a change in the associated species assemblages.

Comparing the damage transition model [below] with the earlier 'natural states' model [p16], it is possible to see that human induced degradation, drainage for example, can induce changes similar to those occurring under changing climatic conditions.

Peat haggs and erosion gullies.

Threat to Biodiversity - Damage to a peatland ironically often increases the number of species locally by introducing a heath habitat. The invading heathland species out-compete those species more characteristic of peat-forming conditions. As a consequence, some of the peat-forming species are now nationally rare, while others are in steep decline. Loss of such species and their associated habitat thereby threatens biodiversity at a national scale.

Of note: **the majority of UK peat bogs are currently in a state of degradation or recovery. Very little is in a state which can be regarded as 'near-pristine'**.

Stages of degradation can be summarised in diagrammatic form.

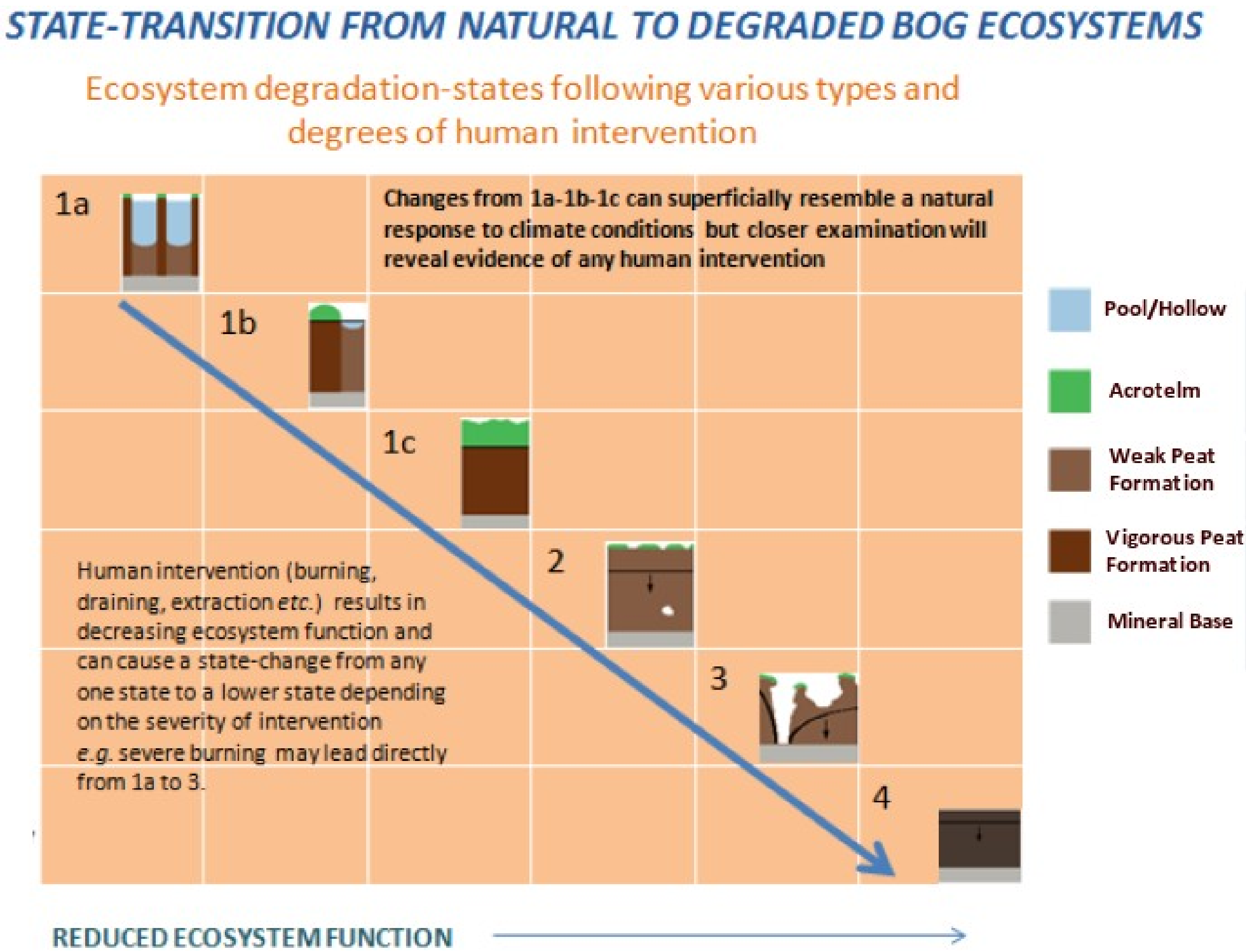


Diagram Source: Linsay, Birnie & Clough IUCN UK Committee Peatland Programme Briefing Note No. 2, 2014

In the Damage Transition Model above the starting points for 1a, 1b & 1c are determined by climate and surface gradient.

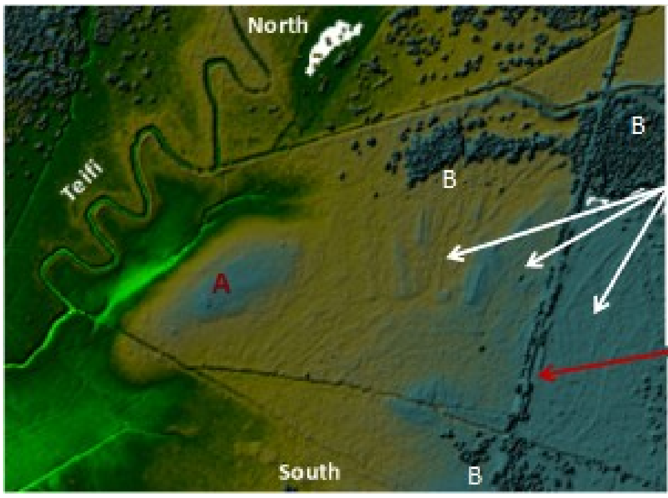
> ***1b & 1c – Drying or drained bog displaying a loss of aquatic zones.***
>
> ***2 - Further drying, or burning – some areas of active bog remain***
>
> ***3 – Hagg and gully eroding bog – fragmentary areas of active bog – losing much catotelm carbon***
>
> ***4 – Haplotelmic bog – all functions associated with an active bog are lost***

***For Cors Goch and Bryniau Pica there is no evidence of exploitation for forestry or economic peat extraction. Therefore, these topics, although important elements of peat bog degradation elsewhere in the UK, are not covered here.**

Bog Degradation - Cors Goch Tregaron.

9.2 Domestic Peat Extraction

Peat has been used as a fuel for thousands of years in the UK. Archaeological evidence exists for its use from Neolithic, Bronze Age and Iron Age sites. On Cors Goch it appears that the historical cutting of peat contributed to the loss of the southern and north eastern units.



The north eastern part of the bog system was ***destroyed long ago through peat digging for domestic use****. [West of Dolyrychain farm] Area around* ***A*** *is a remnant section of degraded bog. A similar loss has occurred in the south near Tregaron.*

T*he* ***linear scars*** *of the old peat workings are still visible on this Lidar image*

B indicates *areas where alder, birch and willow have invaded*

The Carmarthen to Aberystwyth railway line also crosses the area. The track bed was laid down on a thick bed of withies to stop it sinking into the underlying peat.

In terms of the damage transition model stages 1b, 1c and 2 are represented here.

2012 Lidar image of the North Eastern section of Gors Goch, Tregaon.

Historic setting - Residents of Tregaron, Ystrad Meurig and Pontrhydyfendigiad as well as neighbouring farms cut peat on the bog. Records from 1907 suggests that a family would require six loads a year. An earlier reference from the 19th century indicates 'that as much as one man can cut in one day, supplies a cottage hearth for a whole year. If the cottager has children, they may need to cut peat for two or three days.'

Domestic peat cutting on Cors Caron ended in the 1960s. It is the historic extraction that makes it necessary to include a discussion on the nature of the impact of peat extraction on peat bogs.

Ystrad Meurig family cutting peat on Cors Caron. Note the stack of peat turves in the background.

The domestic cutting of peat is traditionally carried out on individual peat 'banks' which take the form of a cut peat face, often no more than 10 or 20m long, but sometimes extending up to 180m across the bog. The peat is cut using a special spade. Each year the face retreats further across the peat bog. The turves are allowed to air-dry, heaped up for collection and then gathered to form a peat stack which represents the annual fuel supply. Such stacks are therefore normally located close to the dwelling. There are often rights or social agreements about the location of individual peat banks within a community. However, on Cors Goch the cutters paid 5 old pence a day to the landowner and by 1907 a load cost six shillings.

Peat cutting needs to make use of a slope. Any attempt to cut a peat face into the flatter, central parts of the raised bog would produce a trench that is unable to drain.

Around a raised bog system like Cors Caron, you would expect to find a wet lagg fen, which represents the natural transition zone between the deep-peat habitat and the mineral soil/deposits of the valley sides. As at other locations in the UK, the lagg fen zone is fragmentary. In the majority of cases this loss has been caused by domestic peat cutting. Extraction is started on the lower margins and slowly advances upslope towards the centre of the raised bog. The cut peat face acts like a one-sided drain with the result that the water table falls in the area of the bog immediately upslope. This results in a loss of function in the acrotelm, along with a general drying out, shrinkage and collapse of the adjacent peat.

Image showing traditional peat cutting with the exposed retreating peat face. 2012, Falkland Islands

The rate of peat extraction outstrips the rate at which peat is deposited. Peat typically accumulates at about 0.5 - 1mm per year, which means a 1 metre depth of peat can take 1,000 years to form. Individual domestic peat banks may appear to have a relatively low impact on the peatland ecosystem, but the **collective impacts over an extended time period** are devastating. Domestic cutting at Cors Caron is implicated in the removal of two domes within the raised bog system. On other bogs JCBs and 'sausage' ploughs have been used to mechanise the process.

In **blanket bog** landscapes, extensive areas of peat have been dug for domestic use for centuries. Remote upland blanket bogs a long way from human habitation were visited using 'peat tracks' and the turves were transported home using ponies, cattle or carried in baskets. Peat gathering was often a community activity, with neighbours coming together to help each other. There are no records of peat digging at Bryniau Pica. There are however, suspicious scars in the landscape, which might be attributed to historic peat cutting.

Need to Know Impacts associated with domestic peat extraction include:

- ***Cutting removes the acrotelm with its actively growing vegetation.***
- ***The cut peat face acts like a drain with the result that the water table falls***
- ***The acrotelm dries and ceases to function and peat formation is inhibited or stops.***
- ***Heather increases in abundance as the bog dries out. Heather is not a significant peat-forming species. Alder, birch, willow and pine also invade the 'dryer' peat.***
- ***Extensive drying creates cracks in the peat that allows rainfall to penetrate and lubricate the base of the peat just above the mineral sub-soil or rock, provoking mobilisation.***
- ***Where peat banks cut into the edge of deep, wet peat systems it can also initiate massmovement [bog slides], and erosion, which then often spreads across the bog.***

Specific Carbon store impacts relating to domestic peat extraction:

- ***Bulk removal and burning – CO_2 lost to atmosphere***
- ***Oxidation of exposed drying peat - CO_2 lost to atmosphere***
- ***Carbon losses from DOC and POC [lesser extent].***
- ***Reduction in future peat production***

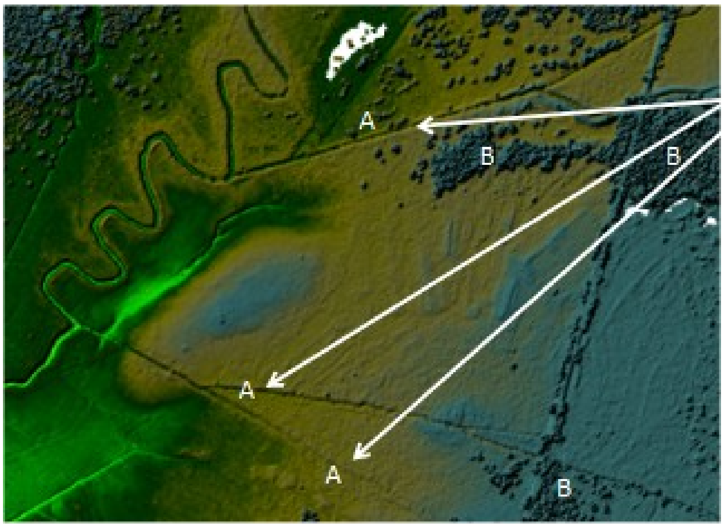
Landscape degradation: ***Not only is the impact clear in bog areas close to settlements like Tregaron, it is also found on isolated upland peat deposits too. Where mechanisation of domestic peat cutting occurs, more dramatic damage to a bog system follows. Such impacts have until now gone largely unnoticed and unrecorded as the heathland ecosystem that invades gives the observer the impression of a healthy ecosystem.***

Bog Degradation - Cors Goch Tregaron.

9.3 Impacts of Drainage

A major impact of drainage is the re-shaping of the bog system

Peat bogs have a **moisture content greater than 95%** in an undisturbed state. Bog surfaces also have areas of standing surface water depending on precipitation/evaporation rates. This water-logging is what creates a peatland and allows it to function. Consequently when humans decide to change the use of the bog area, drainage is generally the first phase. The developer is often disappointed by the lack of apparent impact of the drainage because the anticipated drying effects are limited in extent. Peat within a metre of the drain will still retain more than 80% moisture content by weight. Although disappointing for the developer, this change is sufficient to degrade the bog habitat. In the past, local farmers used Cors Goch in dry periods for grazing and concentrated their attention on improving the margins. However, this changed after World War Two with a general drive towards improving national productivity. Livestock subsidies and improvement grants for marginal areas, promoted by the then Ministry of Agriculture, also helped fuel the drive to improve marginal land.



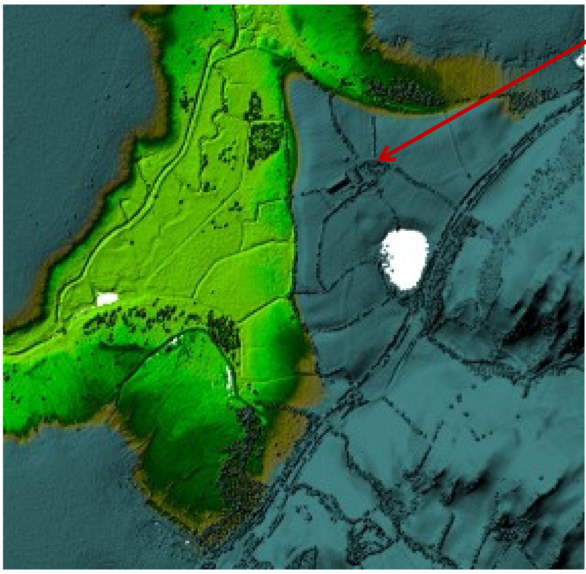
Cors Goch Tregaron - north eastern part of the bog system. [West of Dolyrychain farm]

Drainage channels [A] to improve grazing have resulted in further degradation and in some areas alder, birch and willow have colonised the surface [B].

Although this is a wet area with some peat retained at depth, active peat formation is limited and isolated to small areas.

In terms of the damage transition model stages 1b, 1c and 2 are represented here.

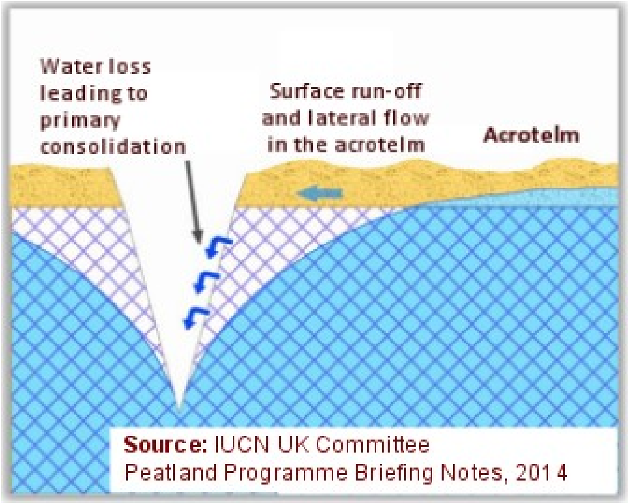
The main long-term effect of drainage is to deflate and re-shape the bog, with major implications for water, carbon and biodiversity. As the rate of change is slow, deflation and change of shape are difficult to record or monitor.



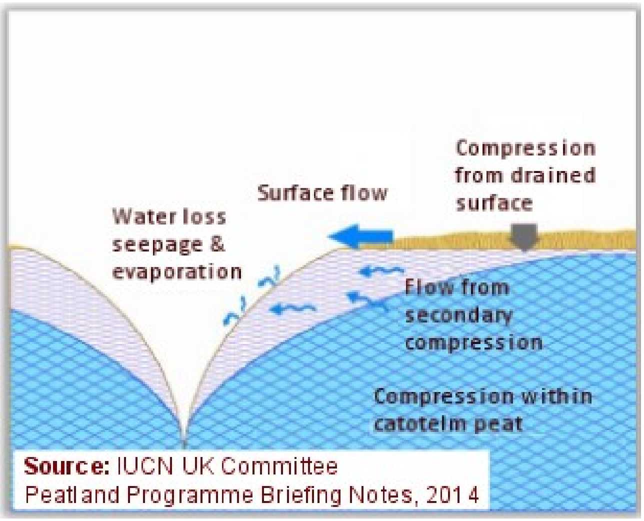
At Maesllyn, ~3km north of Tregaron, the farm has been located on a debris flow and kame terrace at the mouth of a tributary valley. The western fringes of the farm are located on improved bog.

Drainage ditches and hedges/fences are clearly visible on the Lidar image alongside. Peat is preserved at depth, but there is no active peat formation.

Most of the development undertaken on bogs is for agricultural purposes or the extension of upland grouse/deer moors. Therefore, drainage is undertaken to lower the water table to help create a deeper, better aerated soil for exploitation. What makes this so difficult to achieve in a peat bog is that it is only the thin surface acrotelm which can be drained.



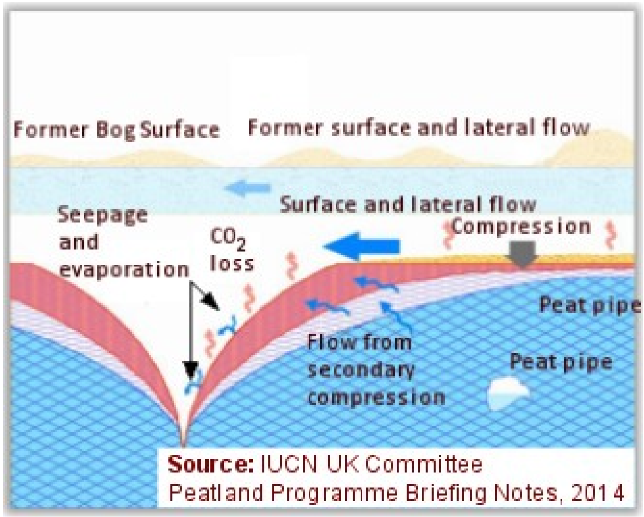
The relatively thin acrotelm layer [10-20 cm] of a bog can lose water vertically and laterally. Consequently, drainage tends to empty the acrotelm of water, sometimes over several hundred metres. From the perspective of the bog ecosystem, however, such effects represent a significant impact. The high and relatively stable water table in the acrotelm maintains the waterlogged environment necessary to support peat-forming conditions. It also allows bog species to resist competition from other plant species which are not normally peat forming.



The impact of drying out the bog - With the drying of the acrotelm and the progressive loss of peat-forming conditions, the acrotelm is no longer capable of providing material to the catotelm. In addition, many of the plant species which invade the dry acrotelm surface have root systems which further dry out the acrotelm and the upper layers of the catotelm.

The catotelm resists drying, but responds instead to water loss by collapse and shrinkage. Water movement in the catotelm is extremely slow, and the lower catotelm layer is particularly resistant to the lowering of the water-table. Drainage tends to promote gravitational loss of water in the catotelm adjacent to the drain only. Consequently, the water table is only lowered adjacent to the drain too. Interestingly, drainage ditches widen over time. This occurs because prior to drainage; water occupied ~ 50% of the catotelm peat volume. It is the loss of this water that results in shrinkage and the collapse of the peat adjacent to the drain. This process is called **primary consolidation**.

Once water has been lost from the peat, the drier catotelm peat adjacent to the drain becomes a heavy load on the peat beneath. The drained layer no longer 'floats' buoyantly within the bog water table. **This load compresses the peat beneath it and squeezes more water from the peat into the drain and allowing the bog surface to deflate further.** This downward pressure can even force water upwards into the drain from the peat below. As a result the entire catotelm peat experiences further subsidence, which is called ***secondary compression***. Secondary compression acts across a steadily widening area beyond the drain and continues as long as drainage is present.

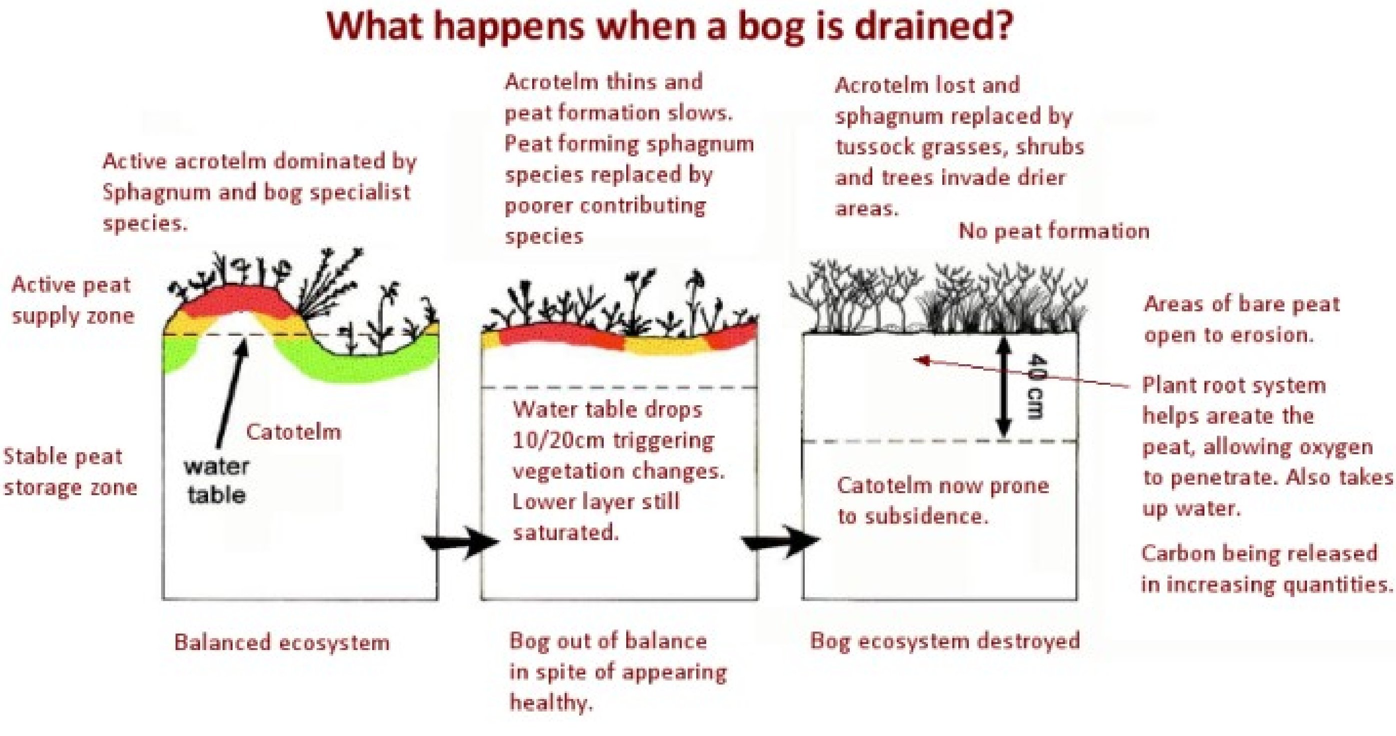


The normal water-logged conditions in the catotelm prevent oxygen-fuelled decomposition. However, once drained, oxygen penetrates the catotelm peat and relatively rapid decomposition takes place. The breakdown produces CO_2, which is lost to the atmosphere and promotes further subsidence. This process is called **oxidative wastage**.

Shrinkage of the peat mass also causes the formation of sub-surface 'peat pipes'. These can work to drain the peat further.

In the fenlands of Lincolnshire and Cambridgeshire, the surface of the fens has deflated by nearly 3m in the last 150 years as a result of large scale drainage programmes. Unfortunately, no reliable data exists for Cors Caron. However, as mentioned above [Domestic Peat Extraction section], a lagg fen peat surrounds raised bog systems like Cors Caron. Observations from other sites reveal that when these areas are drained or removal, over the long-term they cause subsidence across the adjacent raised bog dome. The overall subsidence after the initial rapid effects of primary consolidation indicate that the bog surface subsides by about 1-2 cm per year. Measurements of CO_2 emissions suggest that up to 0.5 cm per year of this may be due to oxidative loss

Impacts on micro-topography and bog vegetation - Bog vegetation is adapted to very stable water table levels. Small-scale groups of species occupy particular zones above or below the water table. Such zones may be no more than 10-20 cm in vertical range. Therefore, a 15 cm fall in the average water table may represent the entire zonal range for a group of species; forcing them to take up new positions within the microtopography, or disappear entirely.



Source: Modified from O'Riley, Trot & Bonn – Field Studies Council & Lindsay, Birnie & Clough IUCN UK Peatland Programme 2014 [Uni East London] The bog surface also loses its **characteristic surface pattern of low ridges and hollows after drainage.**

Where trees colonise raised bogs after drainage, there is evidence that their roots remove water from the system. Water is taken up by roots from the peat and the canopy prevents rainfall reaching the bog surface. In time, the increasing weight of the trees helps to compress the peat, resulting in further subsidence.

Need to Know Impacts associated with draining peat bogs include:

- **Thinning and destruction of the acrotelm with its actively growing vegetation.**
- **Drainage results in the lowering of the water table**
- **Peat formation is inhibited or stops.**
- **Extensive drying creates cracks causing collapse and shrinkage.**
- **Peat surface is lowered.**
- **Heather increases in abundance as the bog dries out. Heather is not a significant peat-forming species. Alder, birch, willow and pine also invade the 'dryer' peat.**

Quantifying the effect of drainage on the bog carbon balance is difficult because:-

- **There are a number of potential pathways for the loss.**
- **Calculating the changing methane to carbon dioxide emissions ratio is difficult**
- **The extent of drainage impacts are not always evident, so identifying the area impacted becomes problematic.**
- **Determining the time frame that applies is similarly problematic.**

Specific Carbon store impacts relating to draining peat bogs:

- **Loss of a functioning acrotelm means loss of carbon-sequestering capacity.**
- **Oxidation of exposed drying peat - CO_2 lost to atmosphere. Greatest alongside drains**
- **Particulate organic carbon [POC] is washed from the face of the drain into water courses. POC losses tend to be greatest when the drains are first dug and during periods of heavy rain.**
- **Dissolved organic carbon [DOC] is released directly into the water forced from the peat by secondary compression. DOC release appears to be most intense during heavy rain following a dry period**
- **If shrinkage pipes are also formed, this provides another route by which POC and DOC can be lost.**
- **The drier nature of the peat reduces methane [CH_4] emissions. Some methane is emitted from the drain bottoms.**
- **Reduction in future peat production**

Landscape degradation: Such impacts have until now gone largely un-noticed and un-recorded as the heathland ecosystem that invades gives the observer the impression of a healthy ecosystem.

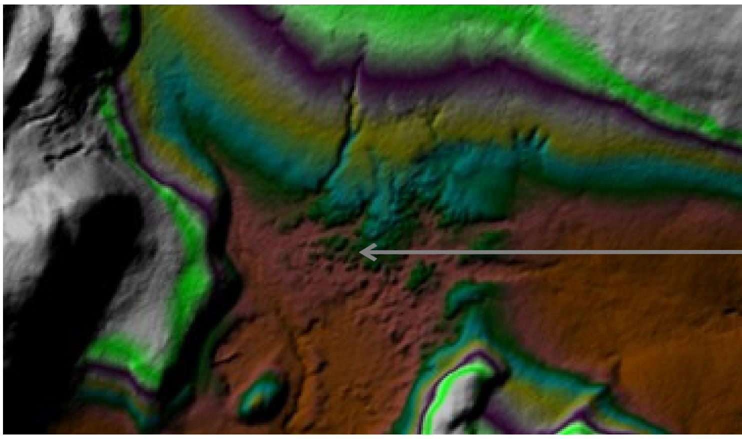
Bog Degradation – Bryniau Pica.

9.4 Impacts of Weathering and Erosion

Bryniau Pica serves as a good example of a blanket bog that is being depleted through weathering and erosion. In fact, this probably began in the Neolithic with early tree clearance. Undisturbed blanket bog peat can have a water content of around 90% to 98% by weight and yet it is draped across slopes of 35˚ or more. Such factors would appear to set up an environment where high rates of weathering, erosion and massmovements are common. In the past, the fact that blanket bog erosion is so widespread in the UK, led observers to the conclusion that collapse and erosion was an integral part of the systems' natural process. However, no convincing evidence has been collected to support this concept. In contrast, research has revealed evidence that links blanket bog weathering and erosion to a variety of human-induced impacts including fire damage, atmospheric pollution, drainage, trampling and overgrazing.

Bryniau Pica - ***1997, Aerial photograph of Llyn Egnant and Bryniau Pica.***

The eroded peat surface of Bryniau Pica clearly stands out in this oblique aerial photograph.



Refined contour shading applied to the 2m Lidar data reveals the surface erosion of upland blanket bogs.

Hagg and gully formation. Note the upstream extension.

2002, 2m DSM Lidar Data of the Bryniau Pica Blanket Bog System

Weathering incorporates the processes of physical breakdown and chemical decomposition of material at or near the earth's surface. Freeze thaw, differential heating and chemical attack reduce particle size and create products that are soluble in water. These particles can then be transported away by massmovement and through the process of ***erosion*** by agents such as water and wind. Uplands usually suffer from higher rates of weathering and erosion because:-

- The climate is more extreme

- Slopes are steeper
- Soils are thin
- Rock is readily exposed at the surface.
- Past processes [e.g. glaciation] have attacked the rock surface and removed surface cover.

High precipitation, more frequent frosts, and greater wind speeds assist weathering and erosion. Steeper slopes provide greater potential gravitational energy aiding massmovements and erosion.

Eroded peat surface. Bryniau Pica, Teifi Pools.

Drying peat haggs, crack and collapse. Dry peat is more susceptible to wind erosion.

In some places the acrotelm has been removed and catotelm peat is weathering and eroding also.

Carbon is being released into the atmosphere and watercourses from this site.

Extensive erosion, visible here, equates to stages 2, 3 & 4 on the degradation transition model.

Vegetation in part, acts as a protective layer, insulating bare rock and soils from these processes**.** Some weathering continues beneath a vegetation cover, permitting soils to stabilise and build up, but erosion tends to diminish. Plant roots biologically weather by splitting rock as roots invade cracks. They also release chemicals [living and dead] which breakdown the parent rock or soil.

Blanket mire landscapes in upland regions like Bryniau Pica **should** serve as good examples of these processes. In such inhospitable landscapes the formation of peat results in the stabilisation of the fragile mineral ground surface and the amelioration of processes associated with weathering and erosion.

Where a gully and hagg system forms, weathering and erosion is exacerbated by:-

- Increasing the surface area available to weathering and erosional processes
- The gaps between the haggs act as conduits by which water drains from one pool to another.
- Over time, further drying and collapse extends the gulley system into a quasi-channel system and encourages headward/upstream erosion.
- On the haggs and dryer hummocks heather, bilberry moss and tussock forming grass [*Molinia caerulea]* invade.

Weathering and erosion together can remove peat at rates of **more than 3 cm per year, or ~3 m per 100 years** where rates are maintained. Losses are closely linked to individual weather events. A single heavy storm, particularly after a long dry spell removes more material in a few hours than sustained periods of moderate precipitation. Over recent years Wales has experienced an increasing frequency of intense precipitation events.

Of note: - Given the widespread nature of blanket bog erosion and its ancient origins, **it is surprising how little ground in the uplands has been completely denuded**. Individual gullies may expose underlying glacial till or bare rock, but it is rarely widespread. The answer appears to lie in the natural blocking up of gullies with peat and sphagnum moss debris. This 'seeds' shallow ponds that allow sphagnum to re-assert its presence via a natural re-wetting of the bog.

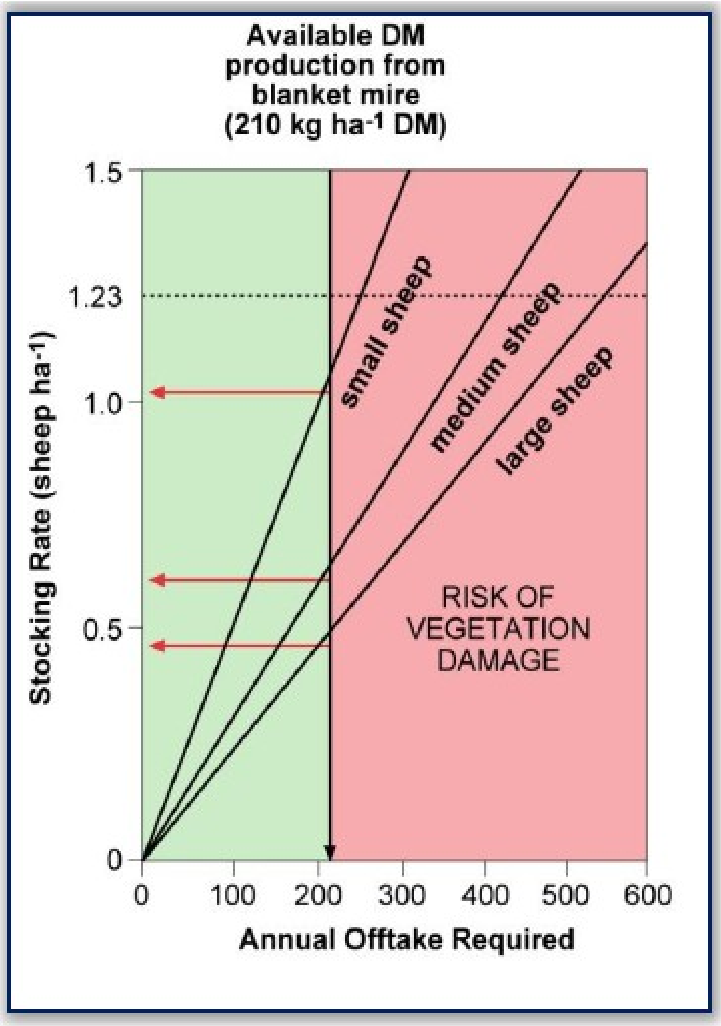
In some areas extensive damage has occurred along the routes of footpaths and tracks as a result of recreational use. This is limited in the Bryniau Pica area.

9.5 Bog Surface trampling and grazing impact [Bryniau Pica] **Watch -** Wind farm Bog Slide

This is the result of long term exploitation of the uplands for grazing. Grazing, browsing and trampling by native wild animals are **components of a natural bog ecosystem.** However, unsustainable levels of grazing and trampling from grazing livestock [sheep, cattle and deer*] have adverse effects on the peatland ecosystem.
*Not a notable issue at Bryniau Pica.

Research evidence suggests that **blanket bog vegetation can sustain wild and/or domestic herbivores at relatively low stocking rates [equivalent to around 0.4 sheep per ha or 1 sheep to the acre].** Higher densities are not sustainable because the total available dry matter produced from a blanket bog ecosystem is low relative to the food requirements of large herbivores. Trampling pressure also becomes significant as it destroys part of this meagre resource. Therefore, even before taking wild herbivore numbers into account, the risk of vegetation damage at low stocking rates, particularly with larger animals is unsustainable.

The graph [right] shows the relationship between sheep stocking rate and annual animal dietary requirements. This issue has now become much more important post-Brexit. In an attempt to make lamb produced on Welsh hill farms more competitive and attractive to foreign markets, hill farmers are being encouraged to produce larger lambs. This means a move away from the traditional hill breeds [Welsh mountain, Ceri & Clun] in favour of bigger, and therefore heavier, breeds. This will increase the grazing and trampling impact on upland areas such as Bryniau Pica.



Source: Lindsay, Birnie & Clough IUCN UK Peatland Programme Briefing Note No. 7. 2014 [Uni East London]

Immediate ecosystem impacts associated with physical damage to the vegetation and bog surface through trampling, grazing and urine/faecal returns.

Livestock often create tracks and small areas of bare peat surface that then become enlarged through erosion. Over many years a **reduction in the annual biomass that is retained in the living surface layer occurs**. This leads to a decline in the thickness of the acrotelm, which makes the site more susceptible to other damaging events.

Keystone Sphagnum species are particularly sensitive to trampling so even the typical small hill sheep breeds cause damage. Evidence suggests that sphagnum cannot withstand more than 1 or 2 trampling events in a year. [Remember, all growth takes place in the head of the plant.] However, in the Welsh uplands the damage caused by grazing has taken place over generations, with a distinct increase in stocking densities post World War Two due to subsidies. A breakdown of the seasonal mixed grazing system of sheep and cattle to a year-round system of sheep only also contributed to the decline**.** Areas where the **level and quality of stock management is low** are also more at risk. For example, much of the blanket bog in Mid-Wales is found on common land and managed under common grazing regulations. In real terms management inputs and investment are poor. Ultimately, it results in a loss of peat forming vegetation and the drying out of the bog surface. In sensitive locations the end-result of persistent high stocking levels is that the acrotelm is lost completely, the drier surface is colonised by non-peat-forming species with expanding patches of bare peat. **The impact on the bog ecosystem is lost because the replacement heather and tussock grasses are healthy.**

In the past, livestock grazing [including deer] has also been intimately associated with burning and drainage of peat bog systems, the former to encourage fresh growth and an 'early bite', the latter to encourage heather or grass growth at the expense of peat-forming vegetation and to minimise the hazard to stock [sheep in particular] posed by very wet ground. Of note, is the input of animal urine/faecal returns, which add additional nutrients to the bog ecosystem. This hits sphagnum particularly and it is unable to compete against those plants that can process higher nutrient levels.

Bog vegetation is sensitive to trampling by humans too. Whether for recreation or scientific research, open country roaming and repeated visits to monitoring points, even if only once a year, can kill the *Sphagnum* in the space of two or three visits.

Summary - Grazing, with its associated trampling, is rarely the only factor involved in the degradation of a bog. Management strategies, such as burning and draining are serious impacts in their own right. It is essential that a reduction in stocking rates to below 0.4 sheep per hectare or the removal of grazing activities altogether must occur to allow the recovery of the vegetation to begin. Heavily-grazed areas which have been largely free from grazing for 10-20 years have been found to show clear signs of recovery in the absence of other pressures.

Sites with a harsher climate, extensive bare peat and high levels of erosion will take longest to recover and may require greater levels of stock reduction and/or wild herbivore control. In all cases, controlled grazing measures should be carried out in concert with other land management measures such as reducing burning and encouraging drain blocking. Any continuation will actively hamper any restoration efforts.

There are no active restoration activities at Bryniau Pica.

9.6 Burning [Cors Goch & Bryniau Pica]

Across the UK, the evidence stored in the peat archive reveals that over the last few centuries burning has been frequent, even in the remotest parts of the country. Usually, this burning has been associated with grazing management for sheep or sporting management for grouse. Both Cors Goch and Bryniau Pica have experienced phased burning as a strategy to improve grazing, primarily for sheep.

Natural fires on bogs are not very common. They are started by lightning strike after a long period of dry weather that has evaporated the surface water and dried out the vegetation cover in places. Natural fires on wet peat bog tend to only burn the surface vegetation and drier features such as hummocks, leaving the wet surface relatively intact. The burning vegetation may, however, cause the peat beneath to catch fire if the peat is unusually dry.

The peat archive reveals that the **time interval** between lightning-induced **natural fires** on an area of peat bog is in the **order of once every 200 – 300 years**. This provides sufficient time for the bog surface and vegetation to recover. If the surface has been burnt to the point where all living *Sphagnum* has been lost, it may take between 80 and 100 years for *Sphagnum* to return on bare burnt peat surface. Full recovery of the ecosystem and its characteristic features is thus a slow process, longer than a single human lifetime.

Human-induced fires on peat bogs, whether as wildfires or as part of a managed burning regime, generally occur 10 times more frequently than natural fires, - roughly every 15-30 years. Over time, such high frequencies lead to a reduction in the Sphagnum cover through increased competition from other species.

Short term studies often focus on the immediate recovery of the vegetation and report a short term carbon gain due to rapid heather growth. This can lead to the mistaken view that burning is beneficial for both the ecology and the carbon store of a bog. However, the damage to the acrotelm leads to the loss of the microtopography. This impacts on the catotelm as it is no longer being supplied with new peat. Further, it is being undermined and dried out through root penetration and water uptake. Aeration increases oxygen and increases carbon loss both to the atmosphere and water courses. In the wetter areas, often dominated by cotton grass methane emissions increase.

Human-induced fires tend to encourage fire-tolerant species at the expense of other peatland species. At fire intervals of around 25-30 years, heather [*Calluna vulgaris*] and a moss carpet develop, which are poor peat formers. At shorter 10-15 year intervals, fire-resistant tussock growth forming species such as cotton grass [*Eriophorum vaginatum*], or purple moor grass [*Molinia caerulea*] prosper. [In Scotland Deer grass tends to be the dominant invader]. Although cotton grass is an important peat-forming species, the tussock growth form appears to be particularly associated with initial stages of peat formation only.
Once peat formation is not possible and the bog becomes 'non active', drying out and surface erosion predominates. A non-active bog means that the bog has lost much of its capacity to respond to external pressures such as climate change and carbon is lost from the store.

10. Restoration

Cors Caron – Raised Bog is currently being restored as an active bog. The main work involves the damming of ditches and the digging of a series of pools to help higher the water table. Monitoring points to register elevational changes and gas emission have also been located across the bog system. To offset trampling damage [details in blanket bog section] livestock is excluded from some areas, while in others; numbers and the duration of the grazing period have been reduced. Raised boardwalks have been built to permit human access for scientific and leisure activities.

Cors Goch bog system at the start of the rehydration programme late 1990s

10.1 Reversing Drainage Effects - Where drains are not maintained, choking with slumped peat and vegetation occurs. Slowly water levels rise and bog vegetation re-establishes its presence. **Conservation management programmes** actively block drains **to speed up this process**. The open ponded water in the drains is infilled by aquatic plant species. However, these species are poor peat formers. Nevertheless, they do perform an essential function in stabilising a high water table across the adjacent bog surface. The wetter bog surface is then capable of supporting more vigorous peat-forming sphagnum species. Bog vegetation starts to lay down fresh peat relatively quickly as recovery takes place. However, it takes a much longer time to offset the subsidence and restore the bog's former elevation and shape.

Using local spoil to block drains is very cost effective at around £6/£20 per dam. Where undertaken correctly, a drain will infill with sphagnum and disappear in about 30 years.

Damming also reduces flow rates, which in turn slows erosion, reduces bank collapse and peat solids being washed into the local water course.

Invading tree species are also being felled and new growth suppressed.

February 2012 with an expanded pool network.
Source: RCAHMW colour oblique photograph of Tregaron Bog. Taken by Toby Driver

10.2 Re-introduction of new plants is an integral element of restoration at some locations. This is usually achieved by transplanting sphagnum plugs from a healthy donor site. **Cors Goch retains large areas of healthy sphagnum and did not require transplants.**

A novel fast-growing Gel Mix - for restoration of lowland bogs, BeadaGel™ has been used to encourage faster establishment and denser coverage than using the traditional sphagnum plugs obtained from a donor site.

However, the water table needs to be consistently maintained within 10-15cm of surface and to be well controlled to prevent both drought and inundation. BeadaGel™ also requires a mulch cover for establishment. It is:

- Available in 11 species
- Produced from tiny amount of parent source material – No damage to donor sites
- The application of gel mix is quick and easy
- Gel mix contains special protectant to assist water holding
- Requires mulch cover - further protection from desiccation e.g. brash, straw

Have no knowledge of BeadaGel™ being used on Cors Goch.

Greenhouse trials showed that water level in the peat column greatly influences the recolonization success of the *Sphagnum*. Most species reacted positively to wetter conditions. When the water level was close to the peat surface [5 cm below] a density of 450 *Sphagnum* plants/m² resulted in some species covering up to 50% of the peat surface in 3 months and 100% in 6 months. *Sphagnum* cover reached 5-10% after 3 months in the drier areas and was generally comparable to results obtained in the field after one season of growth under shade cloth.

Results from this trial, suggest that *S.fallax* should be favoured above *S.fuscum and S.magellanicum* as a pioneer in bog restoration to stimulate rapid colonization and recovery. Other *Sphagnum* species characteristic of ombrotrophic bogs can then re-establish more slowly.

A Canadian model based on the redevelopment of extractive sites takes 10 years to go from bare peat to healthy growth. Here a staged moss transfer technique has been developed:

1. Cotton grass is used as a first stage cover.
2. Followed by sphagnum plugs.

A sphagnum dominated plant cover is re-established over 3-5 years following restoration and biodiversity and hydrology returns to near pre-harvest conditions.

Although peat starts to form relatively quickly, bog surfaces in a state of restoration are net emitters of CO_2 and methane. Methane emissions are particularly high in the first 5/6 years of the programme especially where cotton grass dominates. Carbon sequestration may start after this 5/6 year period, but takes between 20-30 years to optimise.

10.3 Other benefits of re-wetting - The re-establishment of a functioning ecosystem helps to offset flood peaks. Hydrologists consider the Teifi to be a very well behaved system, flood wise, as it suffers from fewer destructive flood events compared to the Dyfi for example. In addition, POC and DOC release into catchment waters is reduced, which in turn lowers water-treatment costs and reduces threat of trihalomethane production.

In Canada beavers have been introduced with mixed results. In some areas the beaver dams naturally help to flood and maintain water levels. Elsewhere, results have been less favourable with beaver excavations being responsible for the lowering of the water table. There is some evidence to suggest that the beavers help to reduce tree numbers, particularly adjacent to the channels and water bodies. There are plans in the UK to release beavers into the wild following a successful captive programme in S W England.

Alternative local case study - Carmarthenshire Bog Programme

10.4 Restoration of Upland Blanket Bogs

Restored areas on former bare peat surfaces can present tough challenges. In some cases these areas are restored to grassland to prevent erosion of the exposed peat. This has sometimes prompted calls for grazing on the new grassland. The grassland phase, however, is but one step in the restoration process and careful management of grazing levels is needed to aid the transition from grassland to active bog.

Restoration after burning - Where one-off burning has been used on degraded peat bogs as part of the restoration programme to remove the invader plants; evidence shows that it also poses a serious risk of damage to species associated with the re-establishment of a functioning acrotelm.

Evidence suggests that it takes between 80 -100 years for a fully-functioning and biodiverse acrotelm to re-establish itself through natural processes. In order to increase the speed of acrotelm development, re-wetting is generally the most effective strategy. Although some mowing of heather and other invasive species may assist.

Re-wetting – damming drains to raise the water table and slow discharge rates within the channel. Slowing discharge rates reduces bank and upstream erosion. Further, it reduces the peat content in the exiting water and helps alleviate flooding downstream.

Other benefits from bog restoration include:-

- The recovery of bog species and bog ecosystem functions.
- Increased carbon uptake and carbon storage.
- Improvements in water quality.
- There may also, depending on catchment context, be benefits in terms of flood mitigation.

Re-introduction of new plants is an integral element of restoration. This is usually achieved by transplanting sphagnum plugs from a healthy donor site.

A novel fast-growing Gel Mix - for restoration of bogs, BeadaGel™, has been used to encourage faster establishment and denser coverage than using the traditional sphagnum plugs obtained from a donor site.

However, the water table needs to be consistently maintained within 10-15cm of the surface; and to be well controlled to prevent both drought and inundation. BeadaGel™ also requires a mulch cover for establishment. At present it is:-

- Available in 11 species
- Produced from tiny amount of parent source material – No damage to donor sites
- The application of gel mix is quick and easy
- Gel mix contains special protectant to assist water holding
- Requires mulch cover - further protection from desiccation e.g. brash, straw

Where this has been trialled in upland areas some reports suggest low survival rates. Also transporting the mulch material to an isolated site can be expensive and requires specialist machines. Consequently, re-seeding large areas is difficult.

Sphagnum plugs - 50,000 plugs of sphagnum moss have been transplanted from an upland Ceredigion donor site, to Dove Stone in the Peak District as part of a bog restoration programme.

Sterling moss Welsh moss gives new hope to degraded Peak District bog

Reseeding of a blanket bog often requires a mini-bund to be dug around the area to retain water and the new sphagnum plugs are protected by mulch. This can be straw transported in from the lowlands, or heather brashings from the uplands. If the sphagnum plugs are being transported in from a distant donor site too, this all adds to the cost of restoration. Given that the location of upland blanket bogs are often isolated, moving people and machinery onto the site on a daily basis is expensive in terms of time and cost. The duration of the projects can also be lengthened by frequent poor weather conditions.

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