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Erosion, restoration and carbon cycling in UK peatlands

Martin describes the dramatic changes that have occurred in UK peatlands, explores the impact of these changes on the carbon cycle, and suggests ways in which work on peatlands might support skills and fieldwork elements of the 2016 A level curriculum.

Accompanying online materials

The study of water and carbon cycling is part of the common core of the 2016 A level specifications. While the study of hydrology and the water cycle is deeply entrenched in school geography, the carbon cycle elements of this core are perhaps less familiar. Study of the global carbon cycle requires understanding of key processes controlling movement of carbon between the major carbon stores, including the oceans, ocean sediments, the atmosphere, soils and the terrestrial biosphere (IPCC, 2013). Although the oceans are the largest carbon stores and so vital to a global understanding, aspects of the terrestrial carbon cycle lend themselves better to local study and fieldwork and are good ways for students to understand human interactions with the carbon cycle.

Land use, land use change, and forestry (often referred to as LULUCF) are recognised in United Nations carbon accounting as potential mechanisms for mitigating climate change. Changes in land use or forestry practice have the potential to change rates of carbon sequestration into soils or forest timber. If carefully managed these changes can be positive and – if suitably verified – can be included in reporting against international carbon targets. In the UK one of the largest stores of terrestrial carbon is organic matter in soil, and the peatlands (highly organic soils) contain over half of total soil carbon. Most of this is stored in the blanket peatlands of Scotland and upland areas of England and Wales. Blanket peats represent 91% of UK peatlands by area, with fenland peat (3%) and lowland raised bog (6%) making up the rest. Fen and raised bog were formerly much more extensive, but have been either exploited for agriculture or mined to provide horticultural peat.

UK peatlands are also places where there has been extensive land cover modification through human action, and so make an interesting case study of the ways in which human activity impacts on the terrestrial carbon cycle. Most schools in the UK are within two hours' drive of a peatland, and many are much closer than that; so these sites are familiar to students and may provide fieldwork opportunities. This article describes some of the dramatic changes which have occurred in UK peatlands over the last 500 years and explores the impact these changes have had on carbon storage and carbon cycling. It also introduces ways in which work on peatlands might be used to support skills and fieldwork elements of the new A level curriculum (see the accompanying online materials on A level fieldwork and teaching data skills through the water and carbon cycle).

UK peatlands

Peat soils store carbon because the rate of fixation of carbon from the atmosphere by photosynthesis in peatland plants exceeds the rate of loss of carbon from the system through decomposition of plant litter and organic matter in the peat and through plant respiration. In mineral soil systems microbial decomposition of litter is typically in equilibrium with the supply of new organic matter as litter. However, in peatland systems high water tables, leading to low oxygen availability, together with cold and acidic conditions, mean that microbial decomposition is reduced. Consequently the soil builds up a very thick organic layer composed of partially decomposed litter: this is peat. In addition to losses of gaseous carbon from microbial decomposition and plant respiration, peatlands may also lose carbon through dissolved carbon losses in drainage waters or through loss of particulate carbon as plant matter or eroded soil are transported in peatland river systems. A typical carbon balance for an upland peatland in the UK is illustrated in Figure 1.

Healthy peatlands accumulate carbon year on year, so over the lifespan of a peatland system large stocks of carbon accumulate at the land surface. Some peatlands in the wettest parts of the UK have been accumulating carbon for most of the Holocene, but most peatlands began to form after about 7000 BP, a period of wetter climate.

Process	Flux (gC m^{-2} yr^{-1})
Net Ecosystem Exchange (NEE) (the balance of photosynthesis against decomposition and plant respiration)	-71
Loss of dissolved organic carbon (DOC) in streams	+26.1
Loss of dissolved CO_2 in streamwater	+1.1
Loss of methane through microbial action	+2.2
Loss of particulate organic carbon (POC) (solid organic soil and plant material) in streams	+2.5
Net carbon balance	**-39.1**

Figure 1: Typical carbon balance for relatively intact UK peatland (figures taken from Billett *et al*., 2010). Note that by convention negative values are flows of carbon out of the atmosphere (carbon sequestration) and positive values represent carbon loss from the peatland. Note also the units, which are gC m^{-2} yr^{-1}, or grams of carbon per metre squared per year.

Human impact through Neolithic forest clearance has also been implicated in the growth of peat cover (see Charman, 2002 for a good discussion of peat initiation). Typical peat depths range from 1–4 metres, so across the UK the total carbon stored in peatland soils is significant. Soils contain around 95 % of the stock of land carbon (the remainder is in live vegetation, mostly trees). Just over half of all UK soil carbon (circa 5.1 billion tonnes) is stored in peatlands, and up to 90 % of this is in Scotland (Ostle *et al.*, 2009).

Peat erosion and carbon cycling

Peatlands in the UK and Ireland are globally distinctive in terms of the degree of peat erosion which they have suffered in the last millennium. Across the UK and Ireland 20–30 % of upland peatlands are impacted by severe gully erosion (Figure 2) (Evans and Warburton, 2007), and in the worst eroded areas extensive bare peat is exposed at the surface (Figure 3). The causes of peat erosion are multiple. Climate change (Little Ice Age storminess and desiccation in the Medieval Climatic Optimum), and multiple human impacts including industrial pollution, overgrazing, and fire have all been implicated as causes of extensive erosion across the uplands. In particular locations a specific cause for local erosion can sometimes be identified, but across the UK and Ireland as a whole it is the coincidence in time and space of a series of natural and anthropogenic factors that have stressed peatland surfaces and enhanced erosive potential: this explains the particularly severe peatland degradation of this region.

Erosion leads to carbon loss from peatlands via three mechanisms:

1. directly, through erosion of peat particles (increasing POC losses)
2. indirectly, through reduction in carbon fixation by peatland vegetation where there is extensive bare peat (decreased Net Ecosystem Exchange)
3. through peat drainage due to gully erosion. This lowers water tables near gullies, which in turn increases rates of organic matter decomposition in the upper layers of the peat and leads to greater dissolved organic carbon losses (Evans and Lindsay, 2010).

In the most eroded peatlands the POC losses alone can be in the order of 70gC m^{-2} a^{-1} (Billett *et al.*, 2010) a magnitude of carbon removal which can shift peatlands from being sites of carbon sequestration to sites of net carbon loss. Note that if POC losses in Figure 1 were on this scale the site would show a net carbon loss.

Peatland drainage and carbon cycling

Over 50 % of the UK's 29,000km^2 of peatland has been impacted by drainage (Milne and Brown, 1997). Drainage, supported by agricultural subsidies with the aim of improving grazing and grouse habitat, was commonplace from the 1950s to the 1990s. Drains are typically closely spaced (10–20m) and circa 50cm deep, and lead to local reductions in water table, both through direct drainage and by channelling overland flow away from downslope areas. Lowered water tables increase the depth of the oxygenated layer near the peat surface and are commonly associated with increases in CO_2 flux from peatlands to the atmosphere (Bain *et al.*, 2011). Increased decomposition of organic matter also leads to greater losses of dissolved organic carbon (DOC) in runoff from drained systems (Worrall *et al.*, 2007). Consequently peatland degradation through drainage also has a negative effect on peatland carbon balances, leading to reduced carbon sequestration.

Figure 2: Severe gully erosion on the southern slopes of the Bleaklow Plateau, Derbyshire. **Photo:** © Martin Evans.

Figure 3: Extensive bare peat exposed in eroded upland peat. **Photo:** © Martin Evans.

Peat restoration and carbon cycling

The unique and severe nature of peat erosion across the UK has led to a long history of efforts to restore these degraded systems. The UK is a world leader in developing approaches to peatland restoration. Restoration efforts have typically aimed to restore natural vegetation to peatland surfaces and/or to raise water tables (Figure 4).

Figure 4: Severe peat erosion on the Kinder Scout plateau, Peak District National Park. In the top right-hand corner of the image the effect of re-vegetation through aerial seeding is clearly visible. **Photo:** © Moors for the Future.

One of the most intensive areas of ongoing restoration is the upland peatlands of the southern Pennines, which are among the most degraded peatlands in the world. Here peatland drainage is driven not by drains but by deep erosional gullies which have been blocked by stone dams (Figure 5). In addition to gullying, peat erosion has created large areas of bare peat with no vegetation cover. Restoration approaches have therefore included industrial-scale seeding of the landscape to restore vegetation cover. Aerial applications of lime, seed and fertilizer create conditions where a nurse crop of utility grass is established (Figure 6). This is not the natural vegetation cover but acts to stabilize the surface so that desirable species such as cottongrass, heather and sphagnum moss can establish. Propagation of heather is encouraged through the application of cut heather mulch, which also aids grass seed germination. Cottongrass plugs are planted in some areas and sphagnum propagules are sprayed onto the surface to encourage sphagnum regrowth. This approach leads to rapid establishment of vegetation cover. As sites are re-vegetated primary productivity is restored. Rather than bare peat, surfaces are covered with vegetation which actively fixes carbon from the atmosphere and adds fresh litter to the peatland surface.

The re-vegetated surfaces are much less prone to erosion, so losses of particulate carbon from the peatland are reduced by an order of magnitude. Re-vegetation therefore has the potential to significantly reduce and/or reverse carbon losses from eroded systems.

Intact peatlands have water tables which are close to the surface for most of the time. Peatland drainage lowers water tables and increases the depth of oxygenated peat, favouring microbes which decompose peat and plant litter. Lower water tables are therefore associated with higher losses of gaseous and dissolved carbon from the peat. In the last two decades blocking of these peatland drains using heather bales or peat blocks to raise water tables has been widely undertaken as part of peatland restoration work.

In the northern Pennines alone 1600km of moorland drains have been restored (Figure 7). In Scotland large areas of peatland which were drained for forestry have been restored through drain blocking and the removal of trees from bog surfaces. Drain blocking is effective in raising peatland water tables, although it may not effect complete hydrological restoration of the peatland (Holden *et al*., 2011). Higher water tables imply reduced CO_2 losses but the impact on dissolved carbon loss is less clear. On average across the UK, the evidence points to reduced DOC flux from drain-blocked sites but there are many sites where the impact is limited or not detectable (Armstrong *et al*., 2010).

Figure 5: Gullies blocked by stone dams. These stabilise the gully floors, promoting re-vegetation and helping to raise water tables. **Photo:** © Moors for the Future.

Figure 6: Aerial seeding of bare peat in the southern Pennines. **Photo:** © Moors for the Future.

Modelling studies can assess the combined impact of peatland restoration on carbon balance. Work by Worrall *et al.* (2009) assessed the impact of the application of best practice restoration approaches across all of the severely eroded peatlands of the Peak District National Park. The model estimated that overall the peatlands area is at present a net sink of carbon, but that 20 % of the area is a carbon source. Maximising restoration across these peatlands could produce a 2.5-fold increase in the size of the carbon sink and mean that no area of the peatlands was a net source of carbon to the atmosphere. The most effective component of restoration in these scenarios was the re-vegetation of bare peat.

Conclusions

Peatlands are sometimes characterised as 'the UK's rainforests' because of the critical role they play in its terrestrial carbon cycle. Human action has significantly reduced the carbon sequestration potential of UK peatlands, but more recently landscape-scale efforts at peatland restoration have begun to reverse this trend. These familiar landscapes, particularly English peatlands, have suffered in part because they are in easy reach of many major urban centres. Where peatland restoration has been undertaken these landscapes now provide local examples of human modification of the terrestrial carbon cycle which can explain and exemplify carbon cycling topics within the new A-level specifications.

Figure 7: Moorland drains are widespread across upland Britain. In this image of peatland restoration in the northern Pennines the drain has been blocked, leaving a series of small pools. **Photo:** © North Pennines AONB Partnership.

References and further reading

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Useful web resources

To see time lapse imagery of peatland re-vegetation over a 13 year period, visit *www.youtube.com/watch?v=WI_HGksxqFo*

Read more about peatland restoration here: *www.moorsforthefuture.org.uk/moorlife* and here *www.northpennines.org.uk/Pages/Restoration.aspx*

The IUCN peatlands report (*www.iucn-uk-peatlandprogramme.org/publications/commission-inquiry/inquiry-findings*) is a useful introduction.

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