THE UK UPLANDS
CARBON SINK OR CARBON SOURCE

A Study by

David Hugill N.Sch

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ABOUT THE AUTHOR

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EXECUTIVE SUMMARY

PEAT – THE NEW BLACK GOLD

Heather moor land in the wetter areas of the UK will be home to an underlying reserve of peat.

- A moor in pristine condition can be a valuable carbon sink with the potential to increase in capacity.
- A badly managed moor can be a carbon source.

My report will highlight different types of restoration currently in progress to repair damage done by acid rain, erosion, overgrazing and wildfire.

The new Heather and Grass burning code is now in operation with land managers having to provide a burning plan before the season starts. It promotes a sustainable use of fire that benefits wildlife and the environment. As a result of these regulations it is unlikely that areas with less than 75% heather cover will be burnt thus giving areas of sphagnum covered peat more protection. A burn that becomes deep seated into the peat can be a disaster, with a worst-case scenario of affecting the composition of the peat, in as much as it is no longer able to absorb water.

A cool burn i.e. one that takes out the vegetation quickly without getting into the peat is more desirable. Frequency of burn to suit all parties is a difficult one with grouse liking young heather balanced with the carbon emissions of frequent burning.

There is a lot of work ongoing regarding best practice on burning and carbon sequestration. This also considers the impact of carbon trading and offsetting in the uplands.

If all the peat in the UK uplands was in the worst condition possible and could be, by restoration, turned into the best condition possible with a value of £8/tonne CO_2 the profit after 20 years would be £1.5 billion, (Worrall 2007).

Only 11% of the UK Land area is planted in trees. This compares to around 39% average in 25 EU member states. It has been estimated that the carbon stored in ½ ha of woodland per rotation is equal to the carbon emissions of one car over a driver's lifetime.
Over a 30 year period, comparing forestry and bio-fuels, land in forestry would sequester 2 to 9 times more carbon than would be avoided by the use of an equivalent amount of land for bio-fuel production, Righelato & Spraklen (2007).

This suggests maintenance and creation of forests would have a greater effect on net GHG emissions than using bio-fuels to replace fossil fuels.

There is around 4 times as much carbon stored in the ground under a forest compared to vegetation carbon stocks but changes in soil carbon are more difficult to quantify than changes in above ground vegetation carbon. This, in my opinion, gives forestry a significant advantage over other carbon resources.

A trip to the USA enabled me to meet American farmers who claimed they could sequester carbon in grassland by increasing the amount of topsoil available. Their strategies to do this were based on the theories of AP Yeomans, an Australian mining ecologist, who claims that the combination of grass and grazing stock is the quickest and most efficient system to put an immediate brake on global warming.

The second leg of my USA trip took me to New Mexico and the international gathering of Holistic Management International. Their mantra of creating healthy soils is now very relevant as a healthy soil can store more carbon. Pulling CO_2 from the atmosphere and storing it in the soil as carbon is, in their view, the most effective way of reducing the 180 Gt carbon legacy of heavy industry.

The final part of my report investigates the potential for micro generation of electricity from wind power and water.

1. INTRODUCTION

Whereas we tend to think of the causes of global warming to be relatively modern day, factors affecting the ability of the uplands to mitigate climate change can be traced back to Mesolithic and Neolithic times, when burning of peat moor land occurred. The number of peat and charcoal layers start to increase after AD 1400, suggesting an escalation of fires after this time. According to historians however it is not until AD 1750 that management plans on systemic burning were implemented.

In those days cattle were the main source of meat, with sheep kept for their wool. Both species grazed on the moors and in bye land. Cattle remains found in peat bogs in the North Pennines suggest large numbers of cattle roamed the moors. As demand for meat increased new dual-purpose sheep breeds were introduced and more burning was carried out to create new pasture.

In 1815 records show this burning was inefficient due to long periods of unproductiveness while heather recovered. Old woody plants burn at high temperature and regeneration is from seed. If heather is not given chance to recolonise, a mat grass dominated moor is the result.

Sporting rights played a part in the heather management with grouse management requiring tall old stands of heather as grouse were stalked whereas shepherds were required to burn around one tenth of their holding annually. In 1853, came a turning point with a new type of gun introduced that enabled grouse to be driven. Bird numbers increased and by 1872 disease was rife.

A Government commission set up in 1880 concluded that too high a bird density on few patches of heather with irregular moorland burning was the cause. It also found that birds living alongside grazing animals suffered less disease. This saw the start of rotational burning by keepers. However, the amount of old heather still prevalent caused large scale fires, which once embedded into the peat made large irregular holes until extinguished by heavy rains.

Moving into the 20th century, by 1950 air pollution had become a real concern slowing down tree growth. Layers of soot found on wall tops are a legacy of this. The introduction of domestic coal burning bans in towns and cities together with the cleaning up of the coal fired power stations has helped. Acid rain, mainly sulphur dioxide, inhibits the growth of mosses including sphagnum and the major peat forming species S. imbricatum has been greatly reduced. This has resulted in increased dominance of cotton grass at the expense of blanket bog and bog mosses. Acid rain is also responsible for the deposition of heavy metals on some moorland and if they were a potential building site (which clearly they are not), planning consent would be refused due to this contamination alone.

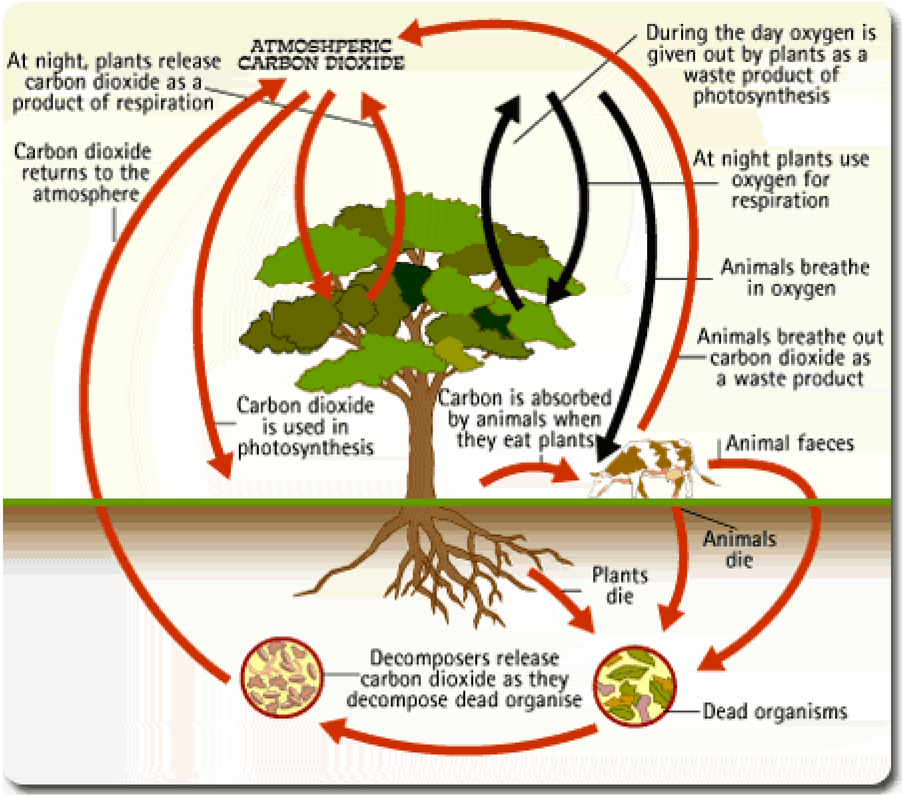
Sheep numbers have caused damage in some areas by overgrazing and can be linked to support packages. Sheep numbers in Wales stood at 11.25 million in 1993 rising to 11.75 million in 1999 on the back of head age payments. As ewe premium was phased out numbers fell to 9.5 million by 2005 a 20% reduction. A similar trend has emerged in Scotland. The reclamation schemes from the 1950s to the 1980s also had an impact. I have seen dairy cows grazing on drained peat land, which alters the natural hydrology and potentially makes them more susceptible to erosion forces.

All these factors have been instrumental over the years in shaping the bio diversity of the uplands and thus causing 80% of all soil carbon losses to come from organic soils.

2. THE ABILITY OF THE UPLANDS TO SEQUESTER CARBON

The Carbon Cycle

Before we look at the ability of the uplands to sequester carbon we need to understand the Carbon Cycle



Plants take in carbon (C) as carbon dioxide (CO_2) by photosynthesis, which converts, to sugars, starches and other material necessary for plants survival. From the plant, carbon is passed up the food chain to all other organisms. This occurs when animals eat plants and animals eat other animals. Both animals and plants release waste as CO_2 in a process called cell respiration. The cells of an organism break down sugars to produce energy for the functions they are required to perform.

CO_2 is returned to the atmosphere when plants and animals die and decompose. The plants absorb this during photosynthesis. In this way the cycle of CO_2 being absorbed from the atmosphere to being released is constantly repeated. In the Carbon Cycle the amount of carbon in the environment is always the same, however, this balance has been upset by the burning of fossil fuels, deforestation etc which has increased atmospheric CO_2 by an estimated 28%.

Methane (CH_4) and Nitrous Oxide (N_2O)

Methane is produced when organic matter decomposes in environments lacking sufficient oxygen.

Natural sources include:
- Wetlands
- Termites
- Oceans

Man-made sources include:
- The mining and burning of fossil fuels
- Digestive processes in ruminant animals such as cattle
- Rice paddies
- The burying of waste in landfills

Total annual emissions of methane are about 500 million tonnes, with man-made emissions accounting for the majority.

Methane is around 21 times as polluting as CO_2.
1 tonne of methane is expressed as 21 tonne CO_2e (CO_2 equivalents)

As with carbon dioxide, the major removal process of atmospheric methane - chemical breakdown in the atmosphere - cannot keep pace with source emissions. Subsequently methane concentrations in the atmosphere are increasing although it would be easier to stabilize than CO_2 and N_2O, requiring only a 10% reduction compared to 80-85% for CO_2 and N_2O.

Tropical soils have been found to be the single most important natural source of nitrous oxide to the atmosphere, although evaporation from the oceans is also a significant source. Man-made emissions, including the burning of organic waste, the use of agricultural fertilisers and industrial production of nylon, may account for up to 40% of total nitrous oxide sources (about 15 million tonnes per year). It is also produced by the soil microbes that play an important role in sequestering carbon.

Nitrous oxide slowly breaks down in the atmosphere under the action of sunlight, but like CO_2 and CH_4, it is slowly accumulating in the atmosphere as a consequence of the extra man-made emissions.

Nitrous oxide is 310 times as potent as CO_2.
1 tonne of N_2O is expressed as 310 tonne CO_2e

Heather Moorland

Heather moorland in the wetter areas of the UK will be home to an underlying reserve of peat. A moor in pristine condition can be a valuable carbon sink with the potential to increase in capacity. A badly managed moor can be a carbon source.

3. CAUSES OF CARBON LOSS IN PEAT LANDS

Causes of carbon loss in peat lands include:

- Gulleys
- Burning

Gulleys

These are areas where the moor has eroded leaving bare ground.

The most dramatic example of erosion that I saw was on the Pennine Way where parts of the path were in a 10 metre deep gully due to erosion caused by the thousands of walkers that complete the 268 mile Pennine Way which starts at Edale in Derbyshire and ends at Kirk Yetholm in the Scottish Borders. I am reliably informed that the site of the walk was level, before this trail was opened.

Overgrazing by sheep has been a bone of contention for a number of years with various support schemes including the rider of overgrazing. It is the damage caused by erosion, i.e. sheep track that can be a source of carbon.

The trampling aspect stimulates denitrification due to reduced soil aeration and could increase N_2O emissions, together with the actual grazing that is changing the biodiversity. In extreme cases heather is replaced by tussock forming graminoid species such as Eriophorum, Angustifolium, Molinia Caerulea and Nardus Stricta. Nardus in particular has short rhizomes giving poor soil binding qualities.

Although every hill is different the consensus of opinion is that a stocking rate of 1 ewe to 2 ha is about right.

I looked at many moors where sheep were excluded completely and they looked good. However most of these were only up to about year five in their exclusion. It is a dangerous practice removing the sheep completely. They provide a good insurance against wildfire with their browsing of emerging shrubs as well as a method of tick control to improve grouse numbers. A wildfire can destroy years of good moor land management.

If all the Peat lands in the UK were to catch fire simultaneously 17 years of our carbon emissions would released.

Burning

The new DEFRA ‘Heather and Grass Burning Code’ came into force on 1st October 2007. It is now in operation, with land managers having to provide a burning plan before the season starts.

It promotes a sustainable use of fire that benefits wildlife and the environment. As a result of these regulations it is unlikely that areas with less than 75% heather cover will be burnt thus giving areas of sphagnum covered peat more protection. A burn that becomes deep seated into the peat can be a disaster with a worst-case scenario of affecting the composition of the peat in as much as it is no longer able to absorb water. A cool burn i.e. one that takes out the vegetation quickly without getting into the peat is more desirable. Frequency of burn to suit all parties is a difficult one with grouse liking young heather balanced with the carbon emissions of frequent burning.

Burning late in the legal season after wet periods in early spring is better for the prevention of soil erosion as the winter freeze thaw cycle leaves soils vulnerable with no vegetation cover.

There is a lot of work ongoing regarding best practice on burning and carbon sequestration.

Investigating the effects of a Moorland Burn

Moor House, Upper Teesdale comprises 74 m^2 of the North Pennine uplands. It is one of the 12 terrestrial Environmental Change Network (ECN) monitoring centres. Research has taken place at Moor House since the 1930's by Universities and Institutes, on a wide range of Upland issues, including several on climate change and carbon dynamics.

An experiment into the effects of the long-term land management practices of repeated burning and grazing on peat land vegetation and carbon dynamics (C) was carried out by the Institute of Natural and Environmental Sciences based at the Lancaster Environment centre.

The following were measured over an 18-month period:

- Plant community composition
- C stocks in soils and vegetation,
- C fluxes

C fluxes are the rate of transfer from one carbon reservoir to another of CO_2, CH_4 and DOC (dissolved organic carbon).

It was found that:

- Both burning and grazing reduced aboveground C stocks
- Burning reduced C stocks in the surface peat

Both burning and grazing strongly affected the types of vegetation, causing an increase in graminoids and a decrease in ericoid sub shrubs and bryophytes relative to unburned and un-grazed controls; this effect was especially pronounced in burned treatments.

Soil microbial properties were unaffected by grazing and showed minor responses to burning, in that the C:N ratio of the microbial biomass increased in burned relative to unburned treatments.

Increases in the gross ecosystem CO_2 fluxes of respiration and photosynthesis were observed in burned and grazed treatments relative to controls. Here, the greatest effects were seen in the burning treatment, where the mean increase in gross fluxes over the experimental period was greater than 40%. Increases in gross CO_2 fluxes were greatest during the summer months, suggesting an interactive effect of land use and climate on ecosystem C cycling.

In conclusion these results show that:

- Long-term management of peat land has marked effects on ecosystem C dynamics and CO_2 flux
- C dynamics and CO_2 flux are primarily related to changes in vegetation community structure.

Organic matter is broken down during a burn and further mineralization may take place, post fire, due to increased microbial action. This is the result of a higher nutrient content of the soil and higher temperature giving a higher pH, therefore faster decomposition. Methanogenic bacteria are reported to be more active under neutral conditions. The natural acidity of an acid soil limits the activity of decomposers which tend to favour a neutral environment.

> Work on a peat land in Minnesota showed an increase in pH from 3.2 to 5.8 increased methane production 1.5 to 2.2 fold, depending on depth of peat, (Williams and Crawford, 1984).

Changing pH can also have an impact on Dissolved Organic Carbon (DOC) as solubility is suppressed by high soil water acidity.

> Experiments have shown that an increase in soil water pH of 0.5 units could cause a 50% increase in DOC (Tipping and Woof 1990).

This could have implications on water quality. There is also evidence to suggest that neutralizing a naturally acidic soil could reduce N_2O emissions short term until the soil microbes adapt to the new conditions. In the longer term organic soils will emit more N_2O than mineral soils.

METHODS OF PEAT LAND RESTORATION

Methods of peat land restoration discussed include:

- Lime and Fertilizer
- Heather Seeding
- Geojute Netting
- Grip Blocking
- Gully Blocking
- Stoning Footpaths

Lime and Fertilizer

These are used to grow a nurse crop of grasses and heather seed that stabilizes the peat (often a fire site) over 3-5 years. While there are green house gas (GHG) issues in using lime and fertilizer it is considered essential to promote grass establishment on areas where grass species do not normally occur.

Heather Seeding

Heather brash sourced locally is applied to flat surfaces spread by hand having been transported to the site in a bale.

Geojute Netting

Steeper slopes are covered in geojute netting which physically holds the peat down and reduces erosion. Geojute is a textile made from natural fibres woven into a loose mesh pattern. It is pegged into the peat and has a life span of 18-24 months after which it will breakdown naturally

Grip Blocking

The aim is to raise the water table, promote new vegetation, reduce peak discharges and also reduce sediment including carbon loss from eroding peat lands.

Moorland gripping was practised extensively through the 1960s and 70s with the assistance of funding from the then MAFF. The belief that drier moorland would lead to better lamb and grouse crops caused a change in hydrology. Water tables were lowered and rainfall reached the main rivers quicker as it ran through the channels rather than through the peat .The grip channels became eroded in some areas.

Grip blocking is done by a series of dams constructed from corrugated material (pictured below) or heather bales. Sedimentation then occurs behind the blockage, which fills in over time and blanket bog habitat becomes re-colonised.

The results are that the peat is prevented from drying out and downstream a river will lose part of its flashiness. One of the problems of this practice is that deep water filled channels are a danger to lambs and grouse chicks leading to losses from drowning. In the North Pennines a tractor mounted reprofiler (pictured below left) has been devised. This pushes the old spoil from the grip down, leaving the effect of a flattened grip.

Tractor mounted reprofiler

(The Darlington and Stockton times)

Blocked grip

Farmers below some of the Pennine catchments are noticing that grip removal or blocking is making a difference to watercourse flows.

Gully Blocking

This works on similar principles to grip blocking. The main objective is to control and stop gully erosion, reduce water discharge and hence prevent sediment loss from peat lands.

Example:

(Moors for the future)

Stoning Footpaths

Impact from continuous footpath use is not as damaging as erosion from fire damage. Indigenous materials are used which are sympathetic to the colour and texture of the area.

5. MOOR LAND RESTORATION CASE STUDIES

5.1 Geltsdale

This work was commissioned by English Nature and the RSPB to help the achievement of favourable conditions on part of Geltsdale and Glendue Fells SSSI in North Cumbria. This is

- an extensive upland area comprised mainly of blanket bog
- an internationally rare habitat
- carries SPA designation
- a candidate Special Area of Conservation

A two-year project has been undertaken by contractor Dinsdale Moorland Services (DMS) in partnership with English Nature, to help restore the condition of the blanket bog in phases. This first entailed the peat to be stabilized to prevent further erosion and to re-vegetate areas of bare and unstable peat and the second aims to restore the water content on the site, improving the quality of vegetation. A substantial number of the grips present on the site were to be lined at the base with a continuous line of baled heather.

Project Detail

The work started in autumn 2002, in a period of wet weather. Following negotiations with a neighbouring landowner, access to the site was given via a forestry track. DMS carried out works to improve access to site which included the construction of a small bridge across a forestry ditch, which had to be cost effective yet robust enough to carry the company's equipment continuously.

A site cabin, all standby machinery complete with maps and compasses in all machines were provided on site, together with heather bales from Barker and Bland. Rather than a sledge, DMS selected a vegetable tractor with carriers to move the heather bales around the site. This system proved extremely efficient, keeping all the bales off the heather surface with very minimal impact on the vegetation or ground structure. A 6 ton 'bogmaster' machine was used instead of the lower powered Soft Trac, a piece of equipment that would not have been suitable for the amount of excavation required.

Time was spent investigating the best method of installing the heather bales and DMS established the best installation process and most economical use of the bales. The company also designed and manufactured a special innovative implement for installation, which was amended slightly so it could also back fill the drains, making the work rate more efficient. The early part of the contract was experimental.

As the project moved on, it became apparent that larger grips made more use of some of the bales, so a need arose to move them further across the moor. To achieve this, DMS used the vegetable tractor with dual tyres and a GPS system on board to navigate across the boggy moor in fog and low cloud. The bales were installed to fill a void, and act as a filtration system and to slow down the water flow. They were installed in a continuous line at either one deep or, in the larger grips, up to three deep and six wide.

The larger grips presented the greatest challenge. These were treated with intermittent fully keyed peat/clay dams and the area between filled tightly with heather bales. The purpose of this was to lift the water table, fill the void, collect silt and stop any further erosion. Any peat left exposed was reprofiled to an appropriate angle and turfed with adjoining vegetation. Now, new sphagnum is growing in the sides of the dams.

On the most environmentally and ecologically sensitive parts of the moor, the contract required that the water level was to be raised to within 150mm of the surface to rewet the surrounding area. Using well-keyed peat/clay dams topped off with vegetation from the grip sides achieved this. On the steeper slopes, peat dams with overflows to the bottom side were used. DMS suggested that these were purposely placed at close intervals to rewet the area below without causing any eroded overflow channels.

On the large filled grips and at the side of a stream DMS carried out ‘drip edge re-profiling’. This is a method of removing the 3-4ft edge, re-profiling to the appropriate angle and re-turfing with existing and surrounding turf. This has stabilized well and eliminated the drip edge and exposed peat completely.

The project will continually be monitored but the results so far are very promising. DMS is now progressing with stage two of the work, which will involve more grip filling, creation of plastic piling and peat dams and drip edge re-profiling over a wide area of Geltsdale.

5.2 Bentham Moor - Grip Blocking

Bentham Moor is situated between Bentham and Slaidburn on the edge of the Forest of Bowland AONB in an area of high rainfall. The area is designated SSSI. Approximately 200acres of the East side of the moor was drained by open grips in the early 70’s.
It was found that, in the original construction, too many of the feeder grips (laterals) were fed into the main grips. This has been compounded by the fact they are on too steep an angle down the hill. This has resulted in a massive erosion problem in the two main grips. All the grips on site started off as approx. 12in-16in deep. The flatter areas and those further up the system are only on average 8-10in deeper but the main grips had eroded to 2-24ft deep and 20ft wide!

The aim of the contract was to divert the water away from these grips and try to fill them in to prevent any more erosion.

Project Detail

The aerial photo of the grip system was studied and from this and the contours, the contractor could establish new watershed to take the water away from the main grip that was to be filled in. The plan was then finalized following a site visit. Although ground conditions were extremely wet at the time, the contract had to be progressed due to funding arrangements. Access to the site was very bad - the HGV low loader could only get within 1 mile of the farm and it was a 1-½ mile walk to the site.

The grips were blocked from the highest point first, working down the hill and a new diverter grip had to be made to take water off a 20-acre section. The client suggested that the grips were pulled in over their total length. Contractors (DMS) proposed a specification change, to stagger pull-ins, creating a more indirect route for any water to try and get through. Further up the system, peat dams were installed with overflows to the bottom side to take excess water across the surface and distribute it over a wider area.

The large grip was dug out in three stages. When the three-stage edge is established the repeating process can start. Soil was dug from the left and placed on the right, compacted and graded to the appropriate angle. The turf from the left was then scraped off in manageable pieces of 6ft x 4ft and placed on a ruffed up surface to knit into place. The turf was then compacted to help stop water from flowing underneath and conserve moisture. The contract was completed in ten days and, to date has been a success with the majority of the water been kept out of the main grip, and where diversions had taken place no extra erosion has occurred.

5.3 Moors for the Future Partnership

Moors for the Future, situated in the Derbyshire Peak District, is a major corporate partnership that is part funded through the Heritage Lottery Fund, delivering a £4.7 million project over five years. It provides an integrated sustainable approach to moor land restoration, conservation, understanding, enjoyment and research. I believe it plays a crucial role in knowledge transfer, from the numerous universities that are doing work on moor land issues, to land managers.

6. FORESTRY

Only 11% of the UK Land Area is planted in trees this compares to around 39% average in 25 EU member states. It has been estimated that the carbon stored in ½ ha of woodland per rotation is equal to the carbon emissions of one car over a driver's lifetime.

> *Over a 30 year period comparing forestry and bio-fuels, land in forestry would sequester 2 to 9 times more carbon than would be avoided by the use of an equivalent amount of land for bio-fuel production, Righelato & Spraklen (2007).*

This suggests maintenance and creation of forests would have a greater effect on net GHG emissions than using bio-fuels to replace fossil fuels. There is around 4 times as much terrestrial carbon stored, compared to vegetation carbon stocks but changes in soil carbon are more difficult to quantify than changes in above ground vegetation carbon. This, in my opinion, gives forestry a significant advantage over other carbon resources.

Measuring Carbon Stored in Trees

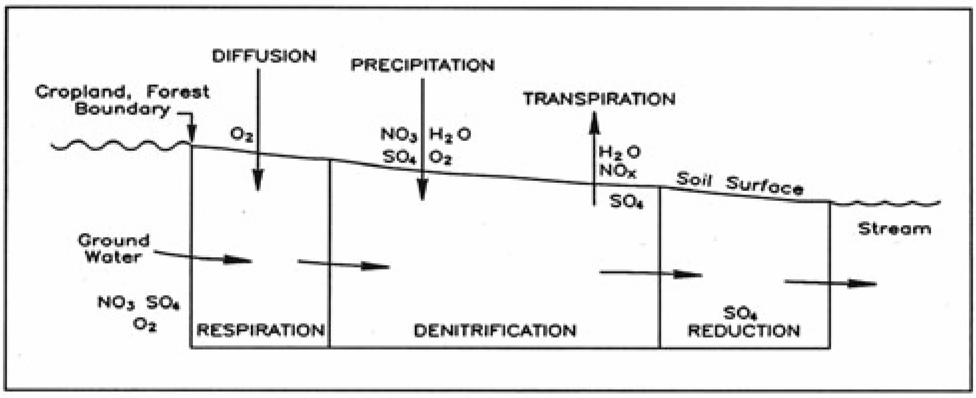
Carbon sequestration from a forest is broadly proportionately to the growth rate of the trees. A tool called Ecological Site Classification can be used to measure carbon stored.

After deciding on the tree species and recording on site data including altitude and soil type, a yield class YC index is reached. This is converted to mass of CO_2 sequestered by the following calculation:

- YC, stem timber volume is converted to dry weight by using tables of wood specific density which range from 0.33 to 0 .45 tonnes/ cu m for softwoods and 0 .49 to 0.56 t/cu m for hardwoods.
- The Carbon content, around 50% is used to convert dry weight to carbon content.
- Carbon content is converted to CO_2 equivalent by a factor of 3.67, which is the ratio of molecular to atomic weight.
- An expansion factor is also added to cover non-stem carbon dependant on age, management and environmental conditions

Riparian Woodland

A buffer zone of native trees up to the edges of rivers and streams is beneficial to both the watercourse and the wider landscape in many ways. Leaf litter falling into the water forms the foundation of the rivers food chain especially in cold, nutrient poor upland streams. Some of this leaf litter plus other tree debris will form particulate and dissolved carbon. A diverse mix of tree species is important as leaves from different tree types decompose at different rates. Alder is a key riparian tree as it can fix atmospheric nitrogen into the soil increasing nutrient input into the watercourses.



Riparian woodland acts as a buffer zone to high nutrient, pesticide or sediment loadings from agricultural land use practices. As summers become hotter the shade given to streams from riparian buffers will become more important for fish such as salmon and trout. Hydraulic roughness from woody debris dams can reduce the rate of progression of flood flows.

Short Rotation Coppice

The logistics of moving product to the end user is difficult in most upland situations. If district-heating schemes can be established in settlements within the uplands there would be a case but these opportunities will be few and far between. There is the issue that large tracts of willow would not sit right with planners in the uplands as planning decisions are based on what is characteristic to the area.

There is a case for setting aside areas for flood water diversion below catchments and SRC would have water table lowering benefits to make these areas more effective but these measures could destroy fragile environments and are not popular with Land Managers and ecologists alike.

7. STRATEGIES FOR CARBON SEQUESTRATION IN GRASSLAND

The opportunities for carbon sequestration in grasslands are not as well documented as for peat and forestry and further work is needed to evaluate their potential. There is very little published research in the UK. One of the reasons could be due to the fact that work done globally started because of the need to combat drought and desertification and this work evolved into mitigating climate change when it became vogue to do so.

To look at work in progress on mitigating climate change using grasslands, I travelled to two parts of the USA; Vermont and New Mexico to meet two groups of farmers and ranchers passionate about mitigating climate change.

Carbon Farmers of America

This is a group of farmers in North East USA, mainly in the state of Vermont, whose goal is to create topsoil and sequester carbon. It is the brainchild of Abe Collins a share milker based at Cinmarron Farm close to St Albans. Abe was brought up the hard way trying to reverse desertification in Arizona. Cinmarron Farm, an organic holding of around 50ha, is home to around 70 dairy cows.

The principles of the Keyline Approach to Agriculture are employed at Cinmarron. Before looking further at how Abe Collins creates topsoil I will describe the Keyline system:

The Keyline system of whole farm planning was developed in Australia in the 1950s, by P.A. Yeomans and his sons, to provide multiple benefits to agricultural landscapes.

The benefits of the Keyline system are:

- Drought-proofing, water storage and water distribution by construction of earth ponds and gravity fed irrigation systems.
- Rapid development of biologically active fertile soil by repeated sub-soiling using the Yeomans plough.
- A perennially abundant landscape that functionally connects farm infrastructure, holistic pasture management and diversified tree crop agriculture.

P.A. Yeomans was a mining ecologist with an uncanny ability to read landscapes. In drought prone dry land Australia during the post war period, poor land management had led to the abuse and erosion of the scant topsoil cover throughout the country. In response to his dominant emerging land use ethic of conservation, Yeomans developed his Keyline design system. In 1953 he published his first book entitled ‘The Keyline Plan’ in which he first began to unveil his theories on soil rehabilitation through water harvesting non-inversion tillage.

Early in his work, Yeomans and his sons used a conventional chisel plough to do their sub soiling, later developing their own specialist design in 1974.

A series of rigid shanks (typically three to five) mounted on a heavy steel frame comprise the bulk of the implement. Typically a coulter disc precedes the shanks slicing open the upper soil layer helping to minimise soil disturbance.

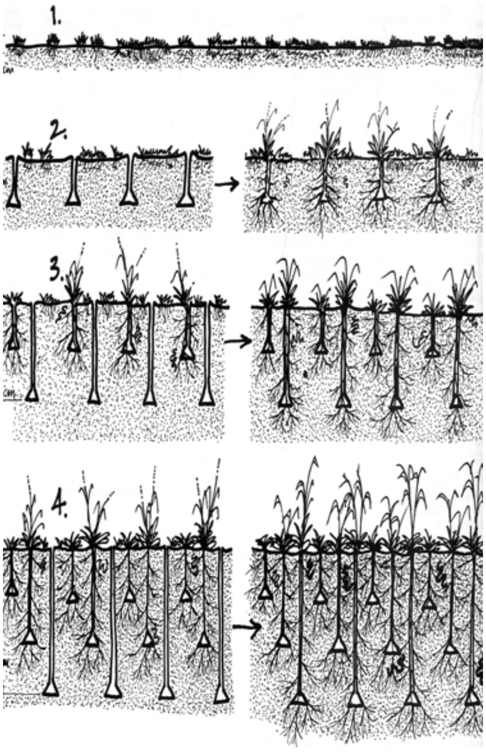
The Keyline plough pictured below differs from traditional sub-soil plough in three main ways:

1. The plough shanks thin profile and knife like edge combined with the sod cutting action of the coulters is engineered to smoothly decompact and aerate subsoil with minimum effects on the pasture surface.

2. Soil layers are not disturbed or mixed by the plough because the angle of action on the foot of the shanks is very light- only 8 degrees as opposed to nearer 25 degrees on a conventional sub-soil plough.

3. Behind the coulter and shanks, a roller bar can be mounted to the rear of the plough acting to lightly compress the de-compacted soil helping to minimize surface disturbance.

Typical soil building programme using the Keyline Plough



1. Soil Test & Remineralise
2. Plough to 2” below hard pan
3. Remove stock for 4-6 weeks
4. Just at onset of flowering:

Hard graze to 2-4”

1. Plough to 2” below new root depth
2. Remove stock for 4-6 weeks
3. Just at onset of flowering:

Hard graze to 2-4”

1. Plough to 2” below new root depth (max out at 12-15”)
2. Remove stock for 4-6 weeks
3. Just at onset of flowering:

Hard graze to 2-4”

Above: Land freshly ploughed land after being grazed

Below: The finished article organic grassland in November 2007 at Cinmarron Farm VT

The enhanced soil conditions that result from cultivation with a Keyline plough, i.e. de-compaction, aeration and improved water filtration provide the potential for significant re-growth of just grazed grass. These plants are then allowed to reach early boot stage before livestock again grazes them. It is this grazing and the subsequent root die back that makes considerable quantities of once living organic matter available to soil life.

The consumption and conversion of this organic matter by soil micro-organisms has been observed to enhance soil fertility, forage production, soil water holding capacity as well as the cultivation of a rich and healthy soil ecosystem. Additionally the development of soil organic matter helps to provide a significant means by which to sequester carbon. The de-compacted soil could also help in reducing nitrous oxide emissions.

Though Key line practices have been adapted throughout Australia, there is a lack of research that actually quantifies the effects of key line cultivation, especially in cooler climates with high rainfall.

While staying at Cinmarron, I had the opportunity to walk part of the farm with Abe. About half the farm drains into a large man-made reservoir which is then trickle irrigated on to the grassland which had been laser levelled. He estimated that some 120 thousand dollars had been invested in his desire to harvest water and irrigate.

A copy of the Keyline plough had been constructed and was used over the whole farm as per key line guidelines. A trial dig in a couple of fields showed an increase in the depth of topsoil. The use of a penetrometer showed a reduction in compaction. Abe used the sense of smell to see whether the soil was living and if microbial activity was good. There was also a teaching facility at the farm for Abe to show to local farmers how to be a good carbon farmer. The nearby university at Burlington was about to start on a 2 year research project on 5 farms evaluating the principles of key line.

Holistic Management International

The second leg of my USA trip took me to New Mexico to the international gathering of Holistic Management International. This organization with its roots in Zimbabwe has been going for 25 years. It has limited personnel in Europe where there are only 2 practitioners but the HMI network is strong in North and Central America as well as Australasia and Africa.

Their mantra of creating healthy soils is now very relevant as a healthy soil can store more carbon. Pulling CO_2 from the atmosphere and storing it in the soil as carbon is, in their view, the most effective way of reducing the 180 Gt carbon legacy of heavy industry.

The holistic principle of grazing management goes back to the historic 'Natural system of the Great Plains' in the US or the Savannas of Africa where massive numbers of animals co-evolved with highly productive rangelands. Large numbers of grazing animals are seen as essential to the health of the grasslands but they must be in large herds constantly moving as they once were by pack hunting predators.

Holistic planned grazing mimics this natural dynamic with domestic animals, bunching them into large herds and timing their movements to eliminate overgrazing of plants while providing the benefit of dung and urine to the soil. Grazing is timed and recovery matched to the features of the vegetation.

Practice and experience worldwide has demonstrated that mimicking nature in this way creates regeneration, an increasing diversity of plant species and erosion is reduced. An added benefit of managing animals in this way is the increase of soil micro fauna especially dung beetles which will benefit carbon storage as they tunnel partially digested grass into the soil. The result of this brief but intense cultivation is an increase in organic matter; the experts say up to 1% increase is achievable.

In global terms a modest ranch of 5000ha can capture 440,000 tons of CO_2 out of the atmosphere (Jones 2006). If 2000 of these ranches or ten million ha were holistic managed, 880 million tons of carbon could be removed representing 0.5% of the 180 Gt industrial legacy.

Globally there are around 4.5billion ha of rangelands and a modest 0.5% increase in 75% of this area would store around 150 Gt carbon. That is close to the target number and this could be achieved by increasing stocking density thus freeing up land to produce food or fuel crops.

The closest grassland management system we have to this in the UK is the paddock or strip grazing of dairy cows in the west or even the constant moving of stock by graziers on Salisbury plain to accommodate military operations. In Southern Europe, the Nomadic Spanish shepherds are performing a similar feat and the Kiwis have devised techno grazing.

While the Uplands of the UK are a world away from the African Savannah I believe this 'out of the box' thinking should be given consideration.

The book 'Priority One' by Allan Yeomans describes in detail strategies to beat global warming. It has a similar take on holistic type grazing practices and calls for more use of mineral fertilizers rather than chemical.

As soon as a grass crop is fully grown a herd of grazing animals should be moved in to quickly eat it out writes Yeomans. After a short period of intensive grazing the grasses have lost their leaves and are unable to breathe in their essential carbon dioxide. As a result they rapidly use the energy in their roots and grow leaves containing chlorophyll, the fine roots are then shed. Any legumes present will shed their nitrogen fixing nodules growing on the roots.

This gives us two feed stocks:

- The grass leaves that feed the stock
- The dead roots that feed soil producing bacteria, fungi and subsequently earthworms that quickly multiply.

Given suitable weather the grass will re-grow quickly producing new leaves with more roots and more nitrogen nodules are formed. Repeating this process will rapidly improve soil fertility. At the same time large quantities of CO_2 are extracted from the atmosphere. The root mass in the soil is equal to the weight of green cover above ground and Yeomans reiterates the claim that the combination of grass and grazing stock is the quickest and most efficient system to put an immediate brake on global warming.

Implementing planned grazing practices that can increase live weight gain or milk yield can also reduce methane emission per kg of milk or meat.

At the HMI gathering I learnt of the following case study, which could quite easily be applied to UK, conditions and can mitigate climate change, improve work life balance and increase profitability.

Case Study:

A family in the state of Montana were struggling to manage their 300-cow suckler herd. After being introduced to holistic management they made the following life changing decisions:

1. Stop using fuel guzzlers	All the machinery was sold leaving only a tractor, pick up and car
2. Stop Haymaking	All hay is purchased locally and is delivered in
3. Stop fertilizing hay fields	Manure from grazing cattle has replaced inorganic fertilizer and the livestock recycle forage back into the soil by stepping on it, increasing soil fertility
4. Native breeds replaced Continental breeds	To avoid having to assist births
5. Stop winter and spring calving	All cows now calve in June onto green grass, which is less work and frees up time in the spring
6. Stop autumn weaning	This reduced their workload further as they only had one herd to feed through the winter with the bonus of heavier calves for the same amount of feed
7. Stop renting summer grazing	This freed up more time to manage the home farm No more stressful phone calls about straying stock, saving on rent
8. Stop chasing cattle	A labour saving grazing cell was created to move cattle around the farm.

Although already practicing some of these principles on my own farm, I will be certainly doing more of them as a result of my study.

Measuring Plant Health

A tool I discovered in the USA was a refractometer, which measures the carbohydrate levels in plant juices and convert this to, what is known as, the BRIX scale of measurement. Plant material is ground up in the refractometer to give a BRIX reading. High Brix plants, including grasses, produce more carbohydrates and around a third of this is as sugars that goes down the root as exudates. When a plant produces more sugars it sends out more roots hence more carbons sequestered.

Extending the grazing season

The traditional May 1st to October 31st grazing has been turned on its head by global warming. There is potential now for producers to keep cattle outside longer by reducing stocking rate and saving on purchased feed by closing up drier pastures on using in the winter.

My work on this project inspired me to do this on my own farm and I have around 40 cows and some followers that have been fed hay rolled out in a different place each day to avoid poaching with some time spent in the spring on Kale, not only has this halved my wintering costs but has significantly reduced my carbon footprint. However I am rare in the fact that I don’t keep any sheep, which would have made saving fields for wintering cattle more difficult.

Liming

Applying high calcium lime can start the carbon cycle. Large quantities of lime were applied to upland areas during the reclamation era of the 1970s and 80s but as support payments for liming were phased out applications were greatly curtailed.

Limestone is calcium carbonate that not only provides calcium but also carbon in a ratio of about 3:1. When this lime is applied, it must be digested by soil biology before the calcium is made available for plant uptake and before the carbonate is released as CO_2. This gas is then reabsorbed by the plant which not only increases yield but also increase the volume of plant residue which is digested by soil biology and increases humus levels which is what actually improves carbon sequestration. Through the carbon cycle therefore the CO_2 released by the soil is returned back to the soil with interest i.e. even more carbons.

Soil Water Storage and Carbon

The soils ability to store water is dependant on a number of factors:

- Rainfall
- Soil depth
- Soil texture
- Mineral content

Changes in the way ground cover is managed affect levels of soil organic carbon which influence soil surface condition, soil structure, porosity, aeration, bulk density, infiltration rates, water storage potential and the amount of plant available water.

Improve any of these and the rain that falls is more effective as it enhances productivity and reduces the risk of erosion and water logging.

Using a soil with a bulk density of 1.2 g/cm^3, this soil will contain stable forms of organic carbon such as humus, which can hold around four times their own weight in water

The following table shows differences in water storage potential and subsequent carbon sequestration with changes in organic carbon (OC) levels

Change in OC Level	change in OC (kg/m^2)	Extra water litres/ha	Extra water litres/ ha	CO_2 sequestered t/ha
1%	3.6	14.4	144,000	132
2%	7.2	28.8	288,000	264
3%	10.8	43.2	432,000	396
4%	14.4	57.6	576,000	528

This table shows an increase of 14.4 litres/m^2 of extra water could be stored in the top 30cm of soil (bulk density 1.2/cm^3) for every 1% increase of soil organic carbon (SOC). When water levels fall the same amount of water will be lost when soil carbon levels fall. There is a linear relationship between soil moisture and levels of soil organic carbon.

Factors that reduce SOC levels and therefore a reduction in the soils ability to store water include:

- Loss of perennial ground cover
- Intensive cultivation
- Bare fallow.
- Continuous grazing

Most farms incorporate one or more of the above practices. As soil carbon levels have fallen by in some cases 3% in the last 50 to 100 years the soils ability to store water has reduced by up to 432,000l/ha. This reduction of SOC by 3% also means that 400t/ha of CO_2 is lost to the atmosphere.

One practice, developed in the Southern Hemisphere to reverse the trend of declining SOC, is yearlong green farming and I believe that some of the principals can be applied to the UK. Roots of actively growing green plants transfer carbon into the soil and in non-growth periods soil must remain covered to prevent carbon losses, an example in an upland situation would be the sowing of forage crops but timing and method of establishment would be critical to avoid bare ground for a long period.

Pasture Cropping

This technique is a relatively new technique introduced into Australia in the nineties and has been shown to have great benefits way beyond increased short-term crop yields from the 1500 land managers that have adopted Pasture Cropping. The technique involves direct drilling cereals into growing pastures and letting these crops grow symbiotically with existing pastures.

The advantages of pasture cropping can be summarised below:

- Greater profit from combining pasture and cropping production.
- Improved soil health
- Improved diversity of the pasture species
- More efficient use of nutrients and less plant diseases.

For the purpose of this report the main advantages are that the ongoing carbon additions from the perennial grass component evolve into highly stable soil aggregates improving soil structure while the short term high sugar forms of carbon exuded by the cereal crop stimulate microbial activity.

CO_2 respired by plant roots and soil microbes slowly moves upwards through the topsoil and increases the partial pressure of CO_2 beneath the crop canopy increasing photosynthesis. Under conventional cropping regimes, the stimulatory exudates from crop roots are cancelled out by cultivation, chemicals and bare earth.

Changing the mindset when reseeding

Drier summers and the rise in input costs could mean a shift from the dominance of ryegrasses that have dominated pastures for number of years. While ryegrass will not be beaten on growth and yield its use has been driven by the quest for high productivity using cheap fertilizer. Our range of natural grasses and herbs here in the UK could provide a valuable tool in improving soil structure and sequestering more carbon. Leys containing a more complex mix of herbs and clovers require lower doses of chemical inputs usually only when establishing. Pasture in drier areas with thin soils could benefit from the sowing of deep-rooted herbal leys, which could grow through July and August in a normal season when ryegrass tends to stop.

The added benefit from a Carbon footprint point of view is the varied depth of root structures. This has the benefit of breaking up soil at different levels and stimulating soil microbial activity, which promotes soil health and the potential to sequester more carbon

Hedgerows

The theory of the ability of a hedge to store carbon is a straightforward one. Around 1.3 metres of above ground biomass will give a similar amount of below ground roots with the potential to sequester carbon as described previously add to that the carbon stored in the plant itself together with the defoliation both natural and mechanical to add to the reserves of organic matter and we have a real tool for sequestering carbon.

Researchers in the Uplands of France have found there are other climate change benefits of a hedge apart from the obvious. Taking a hedge sited perpendicular to a slope the topsoil can gain significantly as the hedge is reached. At the other side of the hedge the thickness is reduced substantially. The hedge can therefore act as a barrier to soil erosion by blocking particles. Above the hedge on the slope the quantity of OC in the soil is relatively uniform. Under the hedge the increase in OC can be up to 3 times higher due to the accumulation of litter.

It has been calculated that in permanent pasture with a hedgerow density of 50m/ha the total OC stored in the soil amounts to 84 tonnes per ha.13% of this OC is stored at the level of the hedges.

8. THE POTENTIAL FOR MICRO GENERATION OF ELECTRICITY

Generating Renewable Electricity from Hydro Power

Electricity is produced when a water flow is channelled through a turbine connected to a generator.

Essential Requirements of a Hydro Electric Scheme:

- Suitable water catchments area
- A good head of water i.e. vertical distance between the reservoir or river to the turbine or a strong flow of water through the system. The height of the head and amount of water available will determine how much power will be produced
- A pipeline or channel to transport the water from the reservoir or river to the turbine
- A turbine, a generator or grid connection and building to house all equipment
- An outflow, where the water is returned to the main water system

The environmental impacts of a small-scale scheme are low and are limited to the visual intrusion of a turbine building and possible damage to fish stocks but this can be overcome by close fitting mesh screens.

The cost of developing a micro hydro scheme is dependent on height of head but with long lifetime of the equipment, high reliability and no fuel costs running costs are low. Funding is available via the Low Carbon Buildings Programme but is currently limited to £2,500 limited to private households.

There are a surprisingly high number of remote dwellings in the uplands that do not have access to the electricity network. Most use diesel-powered generators. Some have converted to hydro with some success. The same costs that were probably prohibitive in originally connecting to the grid would apply when selling power back to the grid therefore the potential of creating revenue from small-scale micro hydro schemes is limited.

Wind Power

- The Suitability of the uplands Wind Turbines
- Micro generation

As wind blows towards a hill it has to rise up the hill to get over it. This moving air joins with the air above it so more air passes over the top so that this can happen wind speed must increase.

As wind speed doubles the energy increases eight times –the cubed rule. Some of the best wind turbine sites are in the UK uplands. The main difference between wind energy and hydro energy is that wind energy is an intermittent energy source so it needs to feed into a storage system such as a battery for small scale uses or into the electricity network. Cost of installation is dependant on the cost of connecting to the electricity network and as for hydro there is a low carbon buildings programme grant amounting to around £1000 per KW installed with the possibly of RDPE (Rural Development Programme for England) funding in some areas for farm based schemes.

The micro-generation wind turbines I visited had very little environmental impact but total revenue which included energy savings on farm, electricity sold to the grid and revenue from Renewable Obligation Certificates (ROCS) for each MWh of electricity generated resulted in around a twenty year payback time.

WIND TURBINE PICS

9. CONCLUSIONS

Peat Land

I have seen plenty of evidence that a pristine site can offer a medium term solution to climate change. On restoration, it is very much work in progress with plenty of work taking place. It is encouraging to see collaboration between the National Park Authorities and landowners. In some parts of the UK there is a skills for restoration work and more specialist contractors need to be identified. Research work is ongoing.

Crucial to the success of peat moor-lands and carbon sinks is the need for definitive guidance on burn frequencies. I believe that the actual intensity of the burn is more important than the frequency. If the root structure is left untouched it provides a vegetated mat to prevent erosion and will help speed up re-growth.

It is important to disseminate the research coming out of the universities down to farmers and land managers. It was a concern at the various conferences I have attended in the past year that I was often the only farmer present. There is a mentality of researchers and environmentalists restoring eroded peat lands to exclude sheep completely rather than simply reducing stocking rates. The hefted hill sheep flock offers a method of reducing biomass quantity on the moor therefore reducing the risk of wildfire. They also give a practical way of controlling sheep tick to help grouse numbers. My trip to the Holistic Management International Gathering suggests removing livestock completely could disrupt the Carbon Cycle. It is important also to consider peat land restoration work as a ‘win win’ situation as a solution to increase carbon sequestration as well as flood mitigation.

Hill sheep flock owners can turn the desire of the environmentalists to reduce stocking rates on moor land to their advantage. I believe a stocking rate of around 2ha per ewe could greatly benefit carbon sequestration as well as restoring profitability to a hill sheep enterprise. The key driver to this statement is the availability of higher level stewardship to the sheep farmer.

The following gross Margin supports this claim:

Single Payment	40.00
HLS@ £20/ha	40.00
HFA @ £7.00	14.00
Lamb +cull sales	33.20
Gross Output	127.20
less	
Variable Costs	9.50
Forage Costs	5.40
Gross Margin	112.30 per ewe

Clearly some flocks would have to disappear, others would have to reduce in number and collaboration would be the key but I strongly believe this is the only way to restoring profitability to this sector.

Forestry

The relative low tree numbers in the UK compared to rest of Europe puts this sector at a disadvantage. Also the time taken for new woodland to be a carbon sink, often as long as 15 years, makes it uncompetitive. The big advantage trees hold over soils both mineral and organic is the fact they are easier to measure in terms of carbon sequestered.

Grassland on Mineral Soils

The real unknown quantity in the UK is the mineral soils of the Uplands often in permanent pasture for many years a potentially a carbon sink. One consideration to bear in mind is that if rotational grazing is best practice for sequestering carbon in grassland we have to consider the implication of N_2O increases as a result of trampling and NH_4 due to more animals.

The main advantage of grassland, in climate change mitigation, is while cereal production is tarnished by the food v fuel debate strategies for reversing global warming can actually increase food production by increasing more milk or meat per ha.

Opportunities for Electricity from Renewable Sources

On farm micro generation from wind is a solution with low running costs and no emissions. The impact of a turbine is low comparable to say, a feed bin but the incentives are currently too low. With more funding available to shorten payback times most upland units could accommodate a turbine. Compare this to a large-scale wind farm. Proposed lowland wind farms meet with stiff opposition from local residents, the sparsely populated uplands often offer no such resistance and can be easy target as once one is allowed planning arguments alone can be more straightforward. The potential carbon losses of site foundations together with associated service roads can go some way to cancel out the benefits of the renewable energy produced.

There are many opportunities available to the uplands connected to climate change:

Marketing

"Telling the story" when selling products such as hill lamb. This marketing strategy has been used to good affect by egg packer Stonegate with its "Respect" brand of eggs which are produced in sheds powered from renewable sources.

Offsetting

The retail example adopted by Carbon Farmers of America is one that could be tried. There is a sector of the public that like to offset their emissions. Why not use the Uplands?
The use of industry to use National Parks as an offset has real potential and work in ongoing to make this happen.

Carbon Credits

Possibly more long term but farmers in North America and Australia are already into this.

Carbon Stewardship

Probably the most straightforward opportunity; delivering of public goods to mitigate the effects of climate change is an easy one to justify.

Before some of these opportunities can be developed further there is a need for the introduction of auditing and accreditation with a body established to oversee this work.

10. RECOMMENDATIONS

Include climate change mitigation in environmental stewardship schemes and make HLS more accessible to moor land flock managers.

To ensure that this money is distributed fairly to all involved in land management some type of Ombudsman type system is needed to avoid the problems currently being experienced by recipients of HLS. While DEFRA is insisting that agreements on commons are formalised with an instruction that all commons have a commoners association there are a number of moors that are not registered as commons and some sort of regulation is needed to include these also. I am confident that there is a real can do attitude regarding moor land restoration. Researchers, NGOs, Land Managers and Government Agencies are all pulling in the same direction however further research on grazing systems and grassland management is urgently needed.

ERDPE funding could be deployed for knowledge transfer on GHG to farmers in upland areas.

Explore the use of sustainable on farm diversification in areas such as bracken composting and heat from bracken pellets. The fact that the bracken area has increased despite the extensive use of Asulum suggests this strategy is not working in some regions and recreating the use of bracken could have long term sustainable benefits.

Look to maintain forest areas which could be under pressure as timber prices increase. Identify areas that could be planted without creating short term carbon losses and reduced areas of food production.

Remove the obstacles that currently discourage farmers from investing in wind turbines.

Introduce protocols for assessing the amount of carbon stored on farm. Once this baseline is established increases in carbon will be easier to ascertain thus clearing the way for offsetting and carbon trading.
Adopt farming champions to communicate best practice for mitigating climate change in the UK and to collaborate with other like minded farmers worldwide.

Look at measures that can increase organic matter in soils although this would be a more broad brush recommendation rather than just confined to the uplands

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