High Weald Woodlands
Carbon Report

Furthering understanding of one of England's Finest Landscapes

A report for the High Weald Joint Advisory Committee

By Sandy Greig, Independent Consultant

July 2010

The High Weald AONB Joint Advisory Committee provides guidance to local authorities and other bodies on implementing the statutory AONB Management Plan and on how local and government policy objectives can be accommodated without damaging the outstanding character of this nationally important landscape.

The High Weald Joint Advisory Committee's Research Programme

Furthering understanding of one of England's Finest Landscapes

The High Weald Joint Advisory Committee's management aims and priorities for the AONB are firmly based on an understanding of the fundamental and defining character of the whole area – that is, those components of natural beauty that have made the High Weald a recognizably distinct and homogenous area for at least the last 700 years and that will continue to define it in the future. It develops its understanding through undertaking work itself, through its specialist team, the AONB Unit, or by commissioning independent reports from others.

The primary purpose of its research programme is to better understand the components of natural beauty. The key components are:

- Geology, landform, water systems and climate: deeply incised, ridged and faulted landform of clays and sandstone. The ridges tend east-west and from them spring numerous gill streams that form the headwaters of rivers. Wide river valleys dominate the eastern part of the AONB. The landform and water systems are subject to and influence, a local variant f the British sub-oceanic climate.
- Settlement: dispersed historic settlements of farmsteads, hamlets and late medieval villages founded on trade and non-agricultural rural industries.
- Routeways: ancient routeways (now roads and Rights of Way) in the form of ridge-top roads and a dense system of radiating droveways. The droveways are often narrow, deeply sunken and edged with trees, hedges, wildflower-rich verges and boundary banks.
- Woodland: a great extent of ancient woods, gills and shaws in small holdings, the value of which is inextricably linked to long-term management.
- Field and heath: small, irregularly shaped and productive fields, often bounded by (and forming a mosaic with) hedgerows and small woodlands and typically used for livestock grazing. Small holdings and a non-dominant agriculture. Distinctive zones of heaths and inner river valleys.

By researching the key components – their history, development, distribution, special qualities, deterioration, damage and loss – we can develop an evidence base for the AONB Management Plan and other AONB policy and guidance.

The JAC's secondary purpose is to better understand how the High Weald landscape can contribute to society – food, energy, water provision, flood protection, recreation, biodiversity and fisheries – without damage to its natural beauty.

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Woodlands and Carbon in the High Weald AONB

Summary and Conclusions

The total area of woodland over 2 hectares in the High Weald AONB is 35,305 hectares (NIWT, 1995) with an estimated further 1765 hectares in woodlands under 2 hectares. The following assessments have been made for these woodlands:

- **Carbon stored in above ground tree biomass – 1,836,733 tonnes**
- **Carbon stored in below ground tree biomass – 551,020 tonnes**
- **Carbon stored in woodland soils – 5,189,800 tonnes**
- **Annual carbon sequestration in above ground biomass – 72,678 tonnes**
- **Annual carbon removal in harvested wood products – 7,300 tonnes**
- **Annual addition to carbon stored in wood products – 3,490 tonnes**
- **Annual carbon gain through fossil fuel substitution – 3,010 tonnes**
- **Annual carbon gain through material substitution – 1,340 tonnes**
- **Annual carbon emissions from woodland operations – 96 tonnes**

The report goes on to consider how the contribution of the woodlands in the High Weald AONB to climate change mitigation could be improved. The following conclusions are drawn:

- The single greatest improvement would be to increase the proportion of woodlands in productive management. If production was increased to 50% of the potential sustainable level of production it would mitigate some 26,000 tonnes of carbon emissions (96,000 tonnes of CO2 emissions) each year.
- Decisions about PAWS restoration on individual sites should consider carbon storage issues alongside biodiversity gains
- Decisions about heathland restoration on individual sites should consider carbon storage issues alongside biodiversity gains.
- Coppice management of woodlands, particularly sweet chestnut coppice for woodfuel, can make a significant contribution to climate change mitigation.
- New conifer plantations are likely to make a greater contribution to climate change mitigation than new broadleaf plantations. However broadleaf species, such as willow, poplar, ash and sweet chestnut, grown on short rotations, can match the performance of conifer species. The impact of future climate change on the growth of different species must be considered, as do the environmental values associated with different woodland types.

A Glossary of key technical terms is given at the end of this report.

Purpose of the Report

This report was commissioned by the High Weald AONB Joint Advisory Committee. It provides a current carbon account for the existing woodlands in the High Weald AONB, including estimates of the net CO2 emissions abatement from direct and indirect fossil fuel substitution. It goes on to consider the impact of woodland management policies on the potential contribution of the woodlands to climate change mitigation. This work will help the AONB achieve its Management Plan objectives relating to climate change.

Background and Introduction

Climate change is widely seen as the greatest long-term challenge facing the world today. There is now overwhelming evidence that global mean temperatures are rising and that man-made emissions of greenhouse gases, primarily CO_2, are the main cause. Woodlands and woodland management have a vital role to play in man's response to climate change as growing trees absorb CO_2 from the atmosphere and store it as carbon. Conversely deforestation is estimated to account for some 18% of current global greenhouse gas emissions.

Policy makers and land managers need to know whether and how their decisions impact on greenhouse gas sequestration and emissions. The starting point for woodlands is to prepare a carbon account, looking at above and below ground carbon storage, and how these stores will change over time. With managed woodlands, emissions associated with forest operations and the amount of carbon removed during harvesting and subsequently stored as wood products need to be assessed. In addition an analysis should include the reduction in CO_2 emissions that result from the direct substitution of fossil fuels with (renewable) woodfuel and the indirect benefit from substituting high embedded energy construction materials, such as brick, concrete and steel, with wood.

Footnote: There are generally considered to be six greenhouse gases (GHGs) contributing to climate change, all with different "global warming potential". CO2 is the most significant and GHG emissions are usually stated as "tonnes CO2 equivalent". This report uses tonnes carbon (C) equivalent which can be converted to CO2 equivalent values by multiplying by 44/12.

Woodlands in the High Weald AONB

By English standards the High Weald has a high proportion (24.6%[1]) of woodland with a predominance of broadleaf woodland, much of which is of ancient origin and therefore of high nature conservation value. The most recent data on the overall nature and composition of the woodlands comes from the Forestry Commission's (FC) National Inventory of Woodlands and Trees (NIWT) the survey work for which was done in 1995. NIWT provides data on the area, type and composition of woodlands of over 2 hectares, based on sample plots. There will clearly have been changes since 1995 although in the context of the High Weald, where the majority of the woodlands are unmanaged, the changes are unlikely to have been substantial. Discussion with local FC officers suggests that the amount of new planting in the High Weald over the last 15 years will probably match the area of woodland lost through felling and restoration to heathland. Updated inventory figures should be available in 2012. The data on woodlands less than 2 hectares is less authoritative but information from the Survey of Small Woodlands and Trees suggests that it would be reasonable to add 5% to the area over 2 hectares to cover them, taking the overall woodland area to 37,070 hectares.

Some key statistics on the woodlands of over 2 hectares in size in the High Weald (from NIWT) are:

- The area of woodland is 35,305 hectares
- 85% of the woodland is classified as high forest
- 19% of the woodland is coniferous
- 66% of the woodland is broadleaved or mixed
- 10% of the woodlands are coppice or coppice with standards
- 9% of the woodlands are managed by the Forestry Commission

Some additional statistics:

- Around 24,500 hectares are classified as ancient woodland sites

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[1] AONB Management Plan, 2nd Edition 2009

- Around 15,750 hectares are classified as ancient and semi-natural
- Around 2,900 hectares of woodland are designated as SSSIs

The geology of the High Weald has strongly influenced both the natural woodland conditions and the choice of plantation species. The underlying geology is formed from sandstone layers interspersed with clay beds. The main soil types formed are brown earths and podsols with surface water gleys in seasonally waterlogged areas.

The woodlands of the High Weald will have been exploited and managed for many centuries and their current distribution and character is a function of their history. The woodlands will have comprised almost entirely broadleaf species until the first extensive conifer plantations were planted in the 19th century on areas of scrub and wooded heath. Subsequently conifers were planted on the heavier clay soils. The most significant conversion of broadleaf woodlands to conifer occurred in the 1950s and 1960s with the introduction of mechanised woodland clearance. Pines and larches were the main species on the free draining sandy soils with spruce Western hemlock and Western red cedar on the clay soils. The main broadleaf species now are oak, ash, birch, sweet chestnut and beech. (Source: PAWS Project Final Report 2008).

Species and age class of the woodland

The NIWT report provides data on the species and age class distribution for the high forest woodland, amounting to 29,877 hectares. It does not provide this information for coppice or coppice with standards. The data is summarised in Table 1 below:

Table 1: Species and age class composition of high forest over 2 hectares in the High Weald AONB

Species Group	Age of Woodland (Planting Year)									Totals (ha)
	1991-1995	1981-1990	1971-1980	1961-1970	1951-1960	1941-1950	1931-1940	1921-1930	Pre-1921	
Pines	647	299	734	1233	1291	642	119	47	186	5198
Spruces	20	121	117	317	138	37				750
Larches	141	55	189	203	82	107	23		28	828
Other/mixed conifer	93	55	51	250	243	151	5	13	30	891
Oak	454	212	22	137	271	282	176	1043	2793	5390

Sycamore/ash /birch	**896**	**987**	**437**	**1060**	**961**	**1543**	**1394**	**1115**	**336**	**8729**
Sweet chestnut	**286**	**197**	**176**	**310**	**225**	**211**	**68**	**125**	**73**	**1671**
Other/mixed broadleaf	**525**	**408**	**489**	**552**	**538**	**1610**	**856**	**843**	**607**	**6428**
TOTAL ALL SPECIES	**3062**	**2334**	**2215**	**4062**	**3749**	**4583**	**2641**	**3186**	**4053**	**29885**

(Note: totals do not add exactly due to rounding)

The Current Carbon Account

This report provides estimates of the following for the woodlands in the High Weald AONB:

- Carbon stored in above ground tree biomass
- Carbon stored in below ground tree biomass
- Carbon stored in woodland soils
- Annual sequestration of carbon in the above ground tree biomass
- Annual removal of carbon in harvested wood products
- Annual addition to carbon stored in wood products
- Annual “carbon gain” through direct fossil fuel substitution
- Annual carbon gain through material substitution
- Annual carbon emissions through woodland management operations and timber transport

The calculation of carbon accounts for woodlands is still in its infancy. This report provides an explanation of the data sources, the assumptions and the methodology used in generating the estimates to aid any future revision in the light of improved understanding or evidence.

1. Carbon stored in above ground tree biomass

The amount of carbon stored in the tree biomass of high forest is shown for broadleaves in Appendix 1 and for conifers in Appendix 2. The assumptions used in generating these estimates are set out in footnotes. In order to reach a figure for the overall amount of stored carbon, values for carbon stored on the coppice and coppice with standards woodland, and in the woodland under 2 hectares must be added. Table 2 shows the estimated overall total:

Table 2: Estimate of carbon currently stored in above ground tree biomass:

Woodland Type	Carbon Stored (tonnes)	% of Total	**Carbon stored per hectare (tonnes)**
Broadleaf in high forest	1,128,944	61.4	51
Conifer in high forest	429,242	23.4	56
Coppice/C with standards	191,084	10.4	52
Woodland under 2 ha	87,463	4.8	52
Total	1,836,733	100	

Notes: Broadleaf and conifer values from Appendices 1 and 2
Coppice assumed to be sweet chestnut, 25 year old, standing at 250m3/ha
CWS standards assumed to be 20% cover of 100 year old oak YC4
CWS coppice assumed to be 40 year old YC4 sycamore/ash/birch
Composition and age of the woodland under 2 ha assumed to the same as for woodlands over 2 ha.

The overall estimate of the amount of carbon stored in above ground tree biomass is **1,836,733 tonnes**, equating to 50 tonnes per hectare for the total woodland area in the High Weald AONB. The figures show very little difference between the amounts of carbon stored in the different woodland types.

2. Carbon stored in below ground tree biomass

There is very little data on the amount of carbon stored in tree roots for different ages and species of tree. Most estimates assume an allometric relationship between above and below ground tree biomass. Using a factor of 0.3 produces a value for the below ground carbon store of **551,020 tonnes** of carbon. This should be regarded as a very approximate estimate which does not reflect the particular woodland composition in the High Weald, in particular coppice woodlands which are likely to have a higher ratio of below to above ground biomass than high forest.

3. Carbon stored in woodland soils

In UK conditions the amount of carbon stored in forest soils almost invariably exceeds the amount stored in the trees, but there is little data on the actual values and none from the High Weald. The amount depends on soil depth, soil type, woodland type and stand age, with peaty soils containing the greatest quantities. There is evidence that the values are higher for long established woodland. A reasonable average value for the soil types in the High Weald would be 140 tonnes per hectare giving a total quantity of **5,189,800 tonnes** of carbon. (Source: Forest Research, in preparation)

4. Annual sequestration of carbon in above ground tree biomass

Estimates of the amount of carbon added annually to the above ground tree biomass (sequestration) for high forest in the High Weald AONB is given for broadleaves and conifers respectively in Appendices 3 and 4. Table 3 gives the estimates for all woodland types:

Table 3. Estimates of current annual carbon sequestration

Woodland Type	Carbon Seq. (tonnes/annum)	% of Total	**Carbon Seq. per hectare (tonnes/annum)**
Broadleaf in high forest	37,073	51.0	1.7
Conifer in high forest	23,525	32.4	3.1
Coppice/C with standards	8,619	11.8	2.4
Woodland under 2 ha	3,461	4.8	2.1
Total	72,678	100	

Notes: See notes for Table 2

Overall current carbon sequestration in the above ground tree biomass is estimated at **72,678 tonnes of carbon per annum**, averaging 1.96 tonnes per hectare per annum.

5. Annual removal of carbon in harvested wood products

There are no data on the quantity of wood products harvested and removed from woodlands in the High Weald. Most of the woodlands owned by the FC are actively managed and there are reasonable estimates for the production from these woods, but they only represent some 9% of the total woodland area. There is some information on the area of privately owned woodland which is currently under a grant aided management scheme, and on the area covered by felling licences, but these do not provide a good basis for estimating annual production. Discussions with FC staff suggest that the total annual harvest might be in the order of 20,000 m3 of conifers and 12,000 m3 of broadleaves but these should only be taken as very rough estimates. What is clear is that the majority of woodlands are not currently being managed for wood production.

Using the above figures for conifer and broadleaf production, the annual removal of carbon from the woodlands as harvested wood products is estimated at **7,300 tonnes.** This represents around 10% of the annual sequestration, and indicates that the net amount of carbon in the High Weald woodlands is increasing at between 60,000 and 70,000 tonnes per annum. See the section below on “Increasing production from the woodlands” for discussion on the potential annual harvest and associated carbon gains.

6. Annual addition to carbon stored in wood products

Discussions with local FC and private sector woodland managers indicates that the current markets for conifers and broadleaves are as set out in Table 4 below. It is estimated that some 50% of conifer production and 20% of broadleaf production is of over 18cm diameter material.

Table 4. Current Markets for Conifer and Broadleaved Wood Products in the High Weald

Diameter Class	Conifer	Broadleaved
Under 18cm	50% woodfuel 25% sawn fencing 15% shavings/bedding 10% round fencing	80% woodfuel 20% fencing (esp. sweet chestnut)
Over 18cm	80% sawn fencing 20% sawn construction	80% sawn construction 20% woodfuel

A reasonable figure for the proportion of sawlog material which ends up as sawn product is 60%, with the residue being used as woodfuel. Using these figures and the estimates of annual production in section 5, the total annual addition to the amount of carbon being stored in wood products is **3,490 tonnes.** This excludes the amount used as woodfuel or shavings and bedding as these are very short lived products. It should be noted that carbon is not stored indefinitely in wood products, eventually the carbon will be returned to the atmosphere.

7. Annual carbon gain through direct fossil fuel substitution

Woodfuel, provided it is produced from sustainably managed woodlands, is a “carbon lean” fuel, with only small quantities of fossil fuel being used in its harvesting, processing and transport. It is therefore reasonable to claim a carbon gain, or carbon emissions avoided, when woodfuel is used as a substitute for non-renewable fossil fuels.
The FC publication “Woodfuel Meets the Challenge” estimates for woodfuel energy output are 1.76 MWH per m3 for broadleaves and 1.4 MWH per m3 of conifers. Using these values and a CO2 emissions value of 425 kg CO2 per MWH from fossil fuels, the carbon gain from broadleaves used as woodfuel is 204 kg of carbon per m3 and for conifers 162 kg per m3. The current annual production of woodfuel from broadleaves and conifers (from Table 4 above) is 6910 m3 and 10,000 m3 respectively. So the total carbon gain from current wood production in the High Weald is **3010 tonnes** of carbon per annum.

8. Annual carbon gain through material substitution

The current annual production of wood used in construction from the High Weald woodlands is estimated at 5810 m3 (see sections 5 and 6 above). A report by the International Institute for Environment and Development (2004) suggests that through the substitution of high embedded energy construction materials such as concrete and brick, a cubic metre of wood saves between 0.2 and 0.27 tonnes of carbon. This estimate has been used in a variety of other publications. Using a value of 0.23 tonnes of carbon saved per m3 of construction timber, the total carbon gain from current annual production in the High Weald is estimated at **1,340 tonnes** of carbon.

9. Annual carbon emissions from woodland management operations and timber transport

Carbon emissions result from a variety of woodland management operations, with the principle sources being timber harvesting machines and timber transport. There are no figures available from the High

Weald (and in any case there is considerable uncertainty about current levels of production – see section 5) but other studies (eg Greig 2008, “A Carbon Account for Kielder Forest” have indicated that a reasonable figure to use would be 3 kg per m3 harvested. Using this figure the total annual emissions from woodland management operations and timber transport would be **96 tonnes** of carbon. This equates to about 1.5% of the net annual sequestration in the High Weald woodlands.

Improving the Contribution of the High Weald’s Woodlands in terms of Climate Change Mitigation

This section of the report examines the opportunities for improving the contribution that the woodlands of the High Weald could make to climate change mitigation, and includes an assessment of the impact of current woodland management policies. The following issues are considered:

- Increasing production from the woodlands
- The relative contribution of conifers and broadleaves
- The relative contribution of coppice and high forest
- The effect of sweet chestnut coppicing on soil carbon
- The impact of PAWS restoration
- The impact of restoring woodland to heathland
- Optimum rotation lengths

1. Increasing production from the woodlands

The most effective way of improving the contribution that the existing woodlands in the High Weald are making to climate change mitigation would be to increase the area of woodland under sustainable productive management. Table 5 shows the potential sustainable production, based on 70% of the current annual increment, from the different woodland types, compared to current production. Note that 70% is a widely used figure for the proportion of the current annual increment that can be removed in thinnings without impacting on long term sustainability.

Table 5. Estimates of potential sustainable production in the High Weald

Woodland Type	Current Production (m3/annum)	Potential Production (m3/annum)	Difference (m3/annum)
Broadleaf in high forest	10,000	99,820	89,820
Conifer in high forest	20,000	78,400	58,400
Coppice/C with standards	2,000	25,130	23,130
Woodland under 2 ha	nil	10,850	10,850
Total	32,000	214,200	182,200

If current production could be increased to 50% of the potential sustainable level of production, ie an increase of 75,100 m3 per annum, and the current product mix was maintained, the total carbon gain would be **26,260 tonnes** carbon per annum, mitigating some **96,290 tonnes of CO2** emissions per annum – see Table 6. This level of production would not significantly impact on the annual sequestration of carbon in the woodlands.

Table 6. Potential carbon gain from increasing production to 50% of the sustainable level. All figures are in tonnes of carbon per annum.

Source of carbon gain	Current carbon gain	Potential carbon gain	Increase
Carbon stored in wood products	3,490	11,690	8,200
Woodfuel	3,010	10,080	7,070
Material substitution	1,340	4,490	3,150
Total	7,840	26,260	18,420

2. Relative contribution of conifers and broadleaves

Table 1 indicates that there is very little difference between the amount of carbon currently stored in conifer and broadleaf woodlands in the High Weald, on a per hectare basis. This is partly a function of age, as the average age of the conifers in high forest is 46 years while the broadleaves average 62 years. The average yield class (a measure of mean annual volume increment) of the conifers is between 2 and 3 times that of the broadleaves, although the carbon density (tonnes per m3) of the broadleaves is higher. Overall conifer stands are sequestering between 1.5 and 2 times as much carbon as broadleaved stands of similar age on a per hectare basis. However sweet chestnut coppice stands are probably sequestering carbon at around the same rate as conifer stands (see 3 below). Note that these estimates are based on above ground biomass only. There are very few relevant studies comparing below ground carbon storage in conifers and broadleaves, and on the long term impact on soil carbon levels.

The contribution of woodland creation to climate change mitigation depends on species choice which in turn depends on site type. In the context of the High Weald new conifer woodlands are likely to significantly out perform (in terms of carbon sequestration) new broadleaved woodlands. An exception to this would be broadleaved species such as willow, poplar, ash and sweet chestnut grown on rotations of between 5 and 25 years. It should however be noted that predicted climate change in the south east of England will result in conditions which will affect the growth if most if not all tree species. Any new woodlands will need to provide multiple benefits, not just carbon storage, which is likely to lead to different choices depending upon location.

3. Relative contribution of coppice and high forest

Table 3 shows that within the existing woodlands, coppice and coppice with standards together are sequestering carbon at a rate between that of conifer and broadleaf high forest. The pure coppice crops are assumed, for the purposes of the calculations, to be 25 year old sweet chestnut (note that the survey was done in 1995 and since then there has been a significant decline in active coppicing). The main FC Bulletin on the yield of sweet chestnut coppice (Bulletin 64, 1987) indicates that it would be reasonable to expect a yield of 10 m3 per hectare per annum for crops grown on a rotation of between 20 and 25 years. Given this rotation length, the higher carbon density of sweet chestnut compared to conifers grown in the High Weald, would indicate that carbon sequestration in sweet chestnut is on a par with that in conifers. The assumptions made for coppice with standards (oak overstorey, sycamore/ash/birch understorey) lead to levels of carbon sequestration similar to those for broadleaf high forest.

The potential contribution of different types of woodland to climate change mitigation depends on the assumptions made about growth and product outturn over many decades. The full potential will not be realised if the woodlands are not managed.

4. The effect of sweet chestnut coppicing on soil carbon

There is no published information or research on the impact of coppicing sweet chestnut on soil carbon levels. There is some evidence from French research that there may be nutrient depletion on certain soil types with intensive coppicing. As a general principle there is likely to be some loss in soil carbon when there is significant ground disturbance, for instance following clearfelling and cultivation prior to replanting. As a silvicultural regime it seems unlikely that coppicing will result in a loss of soil carbon unless there is considerable ground disturbance caused by harvesting and extraction equipment.

5. The impact of PAWS restoration

The progressive restoration of plantations on ancient woodland sites (PAWS) to native woodland is encouraged and supported financially by Government. A PAWS restoration project ran in the High Weald from 2005 to 2008. The recent emergence of climate change mitigation as a policy driver has resulted in some questioning of the policy of PAWS restoration.

In the context of the High Weald, PAWS restoration will normally involve the progressive removal of conifers which had been planted on sites which had previously carried native broadleaved woodland. The impact of restoration, in terms of the potential of the woodland to mitigate climate change, will depend on a number of factors including:

- The age, yield class and quality of the conifers being removed
- The potential growth of and production from the native woodland which is replacing the conifers
- The period over which the restoration is taking place

For illustrative purposes we might consider the choice between yield class 12 Scots pine and yield class 4 oak, over a 100 year period. For simplicity it is assumed that the woods are thinned, that all the under

18cm material (from both species) goes to woodfuel and that all the over 18cm material goes to construction timber. The pine crop is felled and replanted after 60 years. No allowance is made for operational emissions or change to the soil carbon store and only above ground tree biomass has been included.

Table 7. Comparison of carbon gains from 1 hectare of Scots pine and oak over 100 years

Carbon gain	SP YC 12	Oak YC 4
Standing carbon after 100 years (tonnes C)	43	68
Total volume harvested (m3)	798	195
Carbon stored in wood products (tonnes C)	55	10
Woodfuel carbon gain (tonnes C)	87	32
Material substitution carbon gain (tonnes C)	60	9
Total carbon gain (tonnes C)	245	119

Note: Total carbon gain comprises standing carbon, carbon stored in wood products, woodfuel carbon gain plus material substitution carbon gain

In this example the contribution, in terms of climate change mitigation, made by a conifer (Scots pine) stand is more than double that made by a native woodland (oak) stand. This “result” will hold for nearly all permutations of conifer and native broadleaf woodland, mainly because of the superior growth rate of the conifers. However making policy based on these generalities is difficult. There are many complex interrelated issues to consider. The potential benefit to above ground carbon storage needs to be balanced against potential but currently unknown benefits to below ground and soil carbon storage from long established broadleaves and greater biodiversity benefits of native woodland. It is also worth observing that, from the example given, the carbon gain from bringing unmanaged woodland into productive management exceeds the carbon “loss” from PAWS restoration on a per hectare basis.

6. The impact of restoring woodland to heathland

In recent years there has been pressure to remove (particularly conifer) plantations from sites which at a particular time in the past had been relatively open heathland. Substantial areas have been restored to heathland in southern and eastern England, including in the High Weald.

The Forestry Commission conducted a major policy review, including a public consultation exercise, on “Restoring and expanding open habitats from woods and forests in England” in 2008/9 and Government decisions on this issue are expected shortly. The evidence report supporting the consultation dealt with the negative impact, in terms of climate change, of removing forests from heathland. Using as an example a Scots pine yield class 12 crop it estimates that restoration to heathland would result in a reduction in the long term carbon store of 38 tonnes of carbon per hectare and a reduction in the substitution potential of 126 tonnes of carbon per hectare over a 100 year period. The calculation of substitution potential assumed that all the wood is used as woodfuel in a co-fired coal fuelled electricity generation plant, but recognises that the abatement potential would rise by a factor of over 3 if the woodfuel was used for combined heat and power. We should also note that basing the analysis solely on woodfuel rather than building in the carbon gains from carbon storage in wood products and material substitution may result in a conservative assessment of negative impact of heathland restoration.

Table 7 above indicates that a better figure for the loss in carbon abatement potential resulting from heathland restoration would be 245 tonnes of carbon over 100 years. Put into context this is almost twice the “loss” resulting from PAWS restoration. Again however the issues are complex. The impact on below ground and soil carbon has not been considered and other objectives such as biodiversity gain will play a role in individual site decisions.

7. Optimum rotation lengths

The conventional economic rotation length for broadleaf and conifer plantations is around the time of maximum mean annual increment, although rotation length can be extended when there is a price premium for large diameter material. From the perspective of optimising the climate change mitigation potential of woodlands, there is benefit in increasing the proportion of material that goes into long term wood products which are substituting for high embedded energy construction material. This is particularly the case if the wood products are used for energy at the end of the product life. In general terms this suggests that introducing climate change mitigation as a policy driver should encourage longer high forest rotations with greater proportions of sawlog material. With coppice crops, such as sweet chestnut, grown specifically for woodfuel the optimum rotation length will be that which maximises volume production.

Improving the Estimates: Options for Further Work

The results and conclusions from this study could be improved in the following ways:

- Improving the data on the age, composition, stocking and growth rates of the woodlands. The National Forest Inventory data and reports, due in 2013 (?) will provide updated and improved information on all woodlands down to 0.5 hectares.
- Getting better data on current production from the woodlands and the markets for the material.
- Getting better data on below ground carbon storage in tree biomass and soils, as well as the impact of different management regimes on them.

Glossary of Technical Terms

Allometric: a quantitative relationship between key dimensions (in this case between above and below ground biomass of trees).
Mean Annual Increment (MAI): the average rate of volume growth from planting/regeneration to any point of time.
Mitigation (of global warming): actions taken to decrease greenhouse gas emissions, to enhance carbon sinks, or both, or to reduce the extent of global warming.
PAWS: Plantations on Ancient Woodland Sites.
Sequestration (of C or CO2): the removal from the atmosphere of carbon or carbon dioxide through biological or physical processes and their retention in living biomass or wood products.
Yield Class: a measure of the rate of volume increase (expressed in cubic metres of wood per hectare per annum) in a stand of trees: the higher the yield class the faster the rate of growth.

Carbon Stored in Above Ground Tree Biomass in High Forest Broadleaf Woodlands in High Weald AONB (over 2 hectares only)

Woodland Type		Age of Woodland (Planting Year)									Totals
		1991-1995	1981-1990	1971-1980	1961-1970	1951-1960	1941-1950	1931-1940	1921-1930	Pre-1921	
Oak	Area (ha)	454	212	22	137	271	282	176	1043	2793	5390
	Vol/ha (m3)	24	36	79	112	145	176	203	223	242	
	tC/m3	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	
	Total C tonnes	3051	2137	487	4296	11002	13897	10004	65125	189254	299253
Syc/ Ash/ Birch	Area (ha)	896	987	437	1060	961	1543	1394	1115	336	8729
	Vol/ha (m3)	24	78	138	175	209	233	248	258	270	
	tC/m3	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	
	Total C tonnes	5591	20016	15680	48230	52221	93475	89885	74794	23587	423479
Sweet Chest	Area (ha)	286	197	176	310	225	211	68	125	73	1671
	Vol/ha (m3)	24	48	91	136	186	235	280	316	348	
	tC/m3	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	
	Total C tonnes	1510	2080	2524	9275	9207	10909	4189	8690	5589	53973
Other/ Mixed Bdls	Area (ha)	525	408	489	552	538	1610	856	843	607	6428
	Vol/ha (m3)	24	48	91	136	186	235	280	316	360	
	tC/m3	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	
	Total C tonnes	3276	5092	11570	19519	26018	98371	62317	69261	56815	352239
Totals	Area (ha)	2161	1804	1124	2059	1995	3646	2494	3126	3809	22218
	Total C tonnes	13428	29325	30261	81320	98448	216652	166395	217870	275245	1128944

Notes: 1. Oak model is YC 4, 1.7m spacing, with selective thinning
2. Sycamore/ash/birch model is YC 6, 1.7m spacing, with selective thinning
3. Sweet chestnut model is YC 6, 1.7m spacing, with selective thinning
4. Other/mixed broadleaf model is beech YC 6, 1.7m spacing, with selective thinning
5. Area (ha) figures are net (NIWT) so no reduction made for open space, roads etc.
6. Yield model volumes have been increased by X1.2 to allow for below 7cm material.
7. Carbon stored in deadwood not included

Carbon Stored in Above Ground Tree Biomass in High Forest Conifer Woodlands in High Weald AONB (over 2 hectares only)

Woodland Type		Age of Woodland (Planting Year)									Totals
		1991-1995	1981-1990	1971-1980	1961-1970	1951-1960	1941-1950	1931-1940	1921-1930	Pre-1921	
Pines	Area (ha)	647	299	734	1233	1291	642	119	47	186	5198
	Vol/ha (m3)	60	95	161	247	330	400	457	504	552	
	tC/m3	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	
	Total C tonnes	8152	5965	24816	63956	89466	53928	11420	4974	21561	284238
Spruces	Area (ha)	20	121	117	317	138	37	0	0	0	750
	Vol/ha (m3)	54	113	232	358	464	552				
	tC/m3	0.165	0.165	0.165	0.165	0.165	0.165				
	Total C tonnes	178	2256	4479	18307	10565	3370				39155
Larches	Area (ha)	141	55	189	203	82	107	23	0	28	828
	Vol/ha (m3)	78	139	215	271	319	358	388		408	
	tC/m3	0.20	0.20	0.20	0.20	0.20	0.20	0.20		0.20	
	Total C tonnes	2192	1529	8127	11003	5232	7661	1785		2285	39814
Other/ Mixed Cons	Area (ha)	93	55	51	250	243	151	5	13	30	891
	Vol/ha (m3)	72	133	241	340	418	488	542	576	590	
	tC/m3	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	
	Total C tonnes	1406	1536	2581	17850	21330	15474	569	1572	3717	66035
Totals	Area (ha)	901	530	1091	2003	1754	937	147	60	244	7667
	Total C tonnes	11928	11286	40003	111116	126593	80433	13774	6546	27563	429242

Notes: 1. Pine model is SP YC 10, 1.7m spacing, with selective thinning
2. Spruce model is NS YC 14, 1.7m spacing, with selective thinning
3. Larch model is JL/HL YC 10, 1.7m spacing, with selective thinning
4. Other/mixed conifer model is DF YC 12, 1.7m spacing, with selective thinning
5. Area (ha) figures are net (NIWT) so no reduction made for open space, roads etc.
6. Yield model volumes have been increased by X1.2 to allow for below 7cm material.
7. Carbon stored in deadwood not included

Current Annual Carbon Sequestration in Above Ground Tree Biomass in Broadleaved Woodlands in High Weald AONB. (Over 2 hectares only)

Woodland Type		Age of Woodland (Planting Year)									Totals
		1991-1995	1981-1990	1971-1980	1961-1970	1951-1960	1941-1950	1931-1940	1921-1930	Pre-1921	
Oak	Area (ha)	454	212	22	137	271	282	176	1043	2793	5390
	CAI (m3/ha)	3.5	5.3	6.4	6.7	6.7	6.2	5.8	5.2	4.2	
	C seq (t/ha/yr	1.0	1.5	1.8	1.9	1.9	1.7	1.6	1.5	1.2	
	Total C seq (t)	454	318	40	260	515	479	282	1564	3352	7264
Syc/ Ash/ Birch	Area (ha)	896	987	437	1060	961	1543	1394	1115	336	8729
	CAI (m3/ha)	11.4	11.9	9.8	7.3	5.4	3.8	3.0	2.0	1.2	
	C seq (t/ha/yr)	3.0	3.1	2.5	1.9	1.4	1.0	0.8	0.5	0.3	
	Total C seq (t)	2688	3060	1092	2014	1345	1543	1115	557	101	13515
Sweet chestnut	Area (ha)	286	197	176	310	225	211	68	125	73	1671
	CAI (m3/ha)	4.8	7.7	9.0	9.8	10.1	9.8	9.1	8.2	7.3	
	C seq (t/ha/yr)	1.1	1.7	2.0	2.2	2.2	2.2	2.0	1.8	1.6	
	Total C seq (t)	315	335	352	682	495	464	136	225	117	3121
Other/ Mixed Bdls	Area (ha)	525	408	489	552	538	1610	856	843	607	6428
	CAI (m3/ha)	4.2	7.7	9.7	10.1	9.4	8.4	7.4	6.7	5.5	
	C seq (t/ha/yr)	1.1	2.3	2.5	2.6	2.4	2.2	1.9	1.7	1.4	
	Total C seq (t)	579	938	1222	1435	1291	3542	1883	1433	850	13173
Totals	Area (ha)	2161	1804	1124	2059	1995	3646	2494	3126	3809	22218
	Total C Seq (t/year)	4036	4651	2706	4391	3646	6028	3416	3779	4420	37073

Notes: 1. Oak model is YC 6, 1.7m spacing, with selective thinning
2. Sycamore/ash/birch model is YC 6, 1.7m spacing, with selective thinning
3. Sweet chestnut model is YC 6, with selective thinning
4. Other/Mixed broadleaf model is oak YC 6, with selective thinning
5. Area (ha) figures are net (NIWT) so no reduction made for open space, roads etc.
6. Yield model volumes have been increased by X1.2 to allow for below 7cm material
7. CAI = Current Annual Increment

Current Annual Carbon Sequestration in Above Ground Tree Biomass in Conifer Woodlands in High Weald AONB. (Over 2 hectares only)

Woodland Type		Age of Woodland (Planting Year)									Totals
		1991-1995	1981-1990	1971-1980	1961-1970	1951-1960	1941-1950	1931-1940	1921-1930	Pre-1921	
Pines	Area (ha)	647	299	734	1223	1291	642	119	47	186	5198
	CAI (m3/ha)	8.4	12.8	16.3	17.2	16.1	13.9	11.3	8.9	6.0	
	C seq (t/ha/yr)	1.8	2.7	3.4	3.6	3.4	2.9	2.4	1.9	1.3	
	Total C seq (t)	1165	807	2496	4403	4389	1862	286	89	242	15739
Spruces	Area (ha)	20	121	117	317	138	37	0	0	0	750
	CAI (m3/ha)	12.6	21.2	24.5	23.6	21.1	18.7				
	C seq (t/ha/yr)	2.1	3.5	4.0	3.9	3.5	3.1				
	Total C seq (t)	42	423	468	1236	483	115				2767
Larches	Area (ha)	141	55	189	203	82	107	23	0	28	828
	CAI (m3/ha)	14.7	16.9	14.6	11.8	9.8	8.5	7.3		5.9	
	C seq (t/ha/yr)	2.9	3.4	2.9	2.4	2.0	1.7	1.5		1.2	
	Total C seq (t)	409	187	548	487	164	182	34		24	2035
Other/ Mixed Cons	Area (ha)	93	55	51	250	243	151	5	13	30	891
	CAI (m3/ha)	14.4	19.8	20.8	18.7	15.8	12.8	9.9	7.2	5.8	
	C seq (t/ha/yr)	3.0	4.2	4.4	3.9	3.3	2.7	2.1	1.5	1.2	
	Total C seq (t)	279	231	224	975	802	408	10	19	36	2984
Totals	Area (ha)	901	530	1091	2003	1754	937	147	60	244	7667
	Total C seq (t/year)	1895	1648	3736	7101	5838	2567	330	108	302	23525

Notes: 1. Pine model is SP YC 10, 1.7m spacing, with selective thinning
2. Spruce model is NS YC 14, 1.7m spacing, with selective thin
3. Larch model is JL/HL YC 10, with selective thinning
4. Other/Mixed conifer model is DF YC 12, with selective thinning
5. Area (ha) figures are net (NIWT) so no reduction made for open space, roads etc.
6. Yield model volumes have been increased by X1.2 to allow for below 7cm material
7. CAI = Current Annual Increment