Report for the Exmoor National Park Authority

Quantifying Carbon Storage and Sequestration in Woodlands in Exmoor National Park

August 2013

74 Adelaide Road, Glenageary, Co. Dublin, Ireland.
Tel: +353 (0)12808338 Mobile: +353 (0)860305236
Email: sandygreig@eircom.net

Quantifying Carbon Stored in Woodlands in Exmoor National Park

Executive Summary

1. The Forestry Commission National Woodland Inventory (1999) shows the area of woodland over 2 hectares in Exmoor National Park (ENP) as 8,331 hectares. A recent but incomplete inventory suggests that the area of woodland over 0.5 hectares is currently 9,300 hectares. From the 1999 inventory, 34% of the woodland is conifer and 66 % is broadleaved. Using the 1999 inventory data the following estimates of carbon storage, sequestration and emissions have been developed:

- **4,183,840 tonnes of CO2 are currently stored in above and below ground tree biomass in the woodlands in ENP, of which 18% is in conifers and 82% in broadleaves. In addition just over 1 million tonnes of CO2 are stored in trees in hedgerows and free standing trees.**
- **Current sequestration in tree biomass amounts to 48,320 tonnes of CO2 per annum, of which 52% is in conifers and 48% in broadleaves.**
- **25,750 tonnes of CO2 are currently being removed in harvested wood products per annum. The current net annual sequestration (increase in tree biomass minus removals) is estimated as 3.7 tonnes of CO2 per hectare for conifers and 3.9 tonnes of CO2 per hectare for broadleaves.**
- **17,300 tonnes of CO2 is currently being added to the amount stored in finished wood products each year. In addition there is a “carbon gain” of 3,350 tonnes and 7,520 tonnes of CO2 from direct (woodfuel) and indirect fossil fuel substitution respectively.**
- **The net contribution to greenhouse gas emissions reduction from existing woodlands in the National Park is estimated at 50,230 tonnes of CO2 per annum. Of this 55% comes from conifers and 45% from broadleaves.**

2. The net carbon gain of 50,230 tonnes of CO2 per annum equates to 14% of the total annual emissions within ENP. There is scope to improve the carbon performance of existing woodlands although it is beyond the remit of this report to estimate what a realistic target might be.

2. Net carbon gains from 3 different woodland creation models appropriate to the National Park over a 100 year period were estimated as:

- **Productive conifer – 1351 tonnes CO2**
- **Native broadleaf – 561 tonnes CO2**
- **Productive broadleaf – 1027 tonnes CO2**

4. Assuming an equal mix of the 3 woodland creation models, a planting programme of 180 hectares per annum would generate net emission reductions of 1,760 tonnes of CO2 per annum. If this programme was continued for 20 years the long term emissions reduction would amount to 35,280 tonnes of CO2 per annum, some 10% of the current GHG emissions in the National Park.

Quantifying Carbon Stored in Woodlands in Exmoor National Park

1. Purpose of the Report

This report provides estimates of carbon storage, sequestration and emissions associated with the woodlands and woodland management in Exmoor National Park (ENP). The report was commissioned by the Exmoor National Park Authority to provide a clearer understanding of the amounts of carbon currently stored in ENP woodlands and the actual and potential role of existing and new woodlands in mitigating climate change through a reduction in net carbon emissions.

2. Background

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. Forests and forest 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 between 10% and 20% of current global greenhouse gas emissions.

Policy makers and land managers need to know how their decisions impact on greenhouse gas sequestration and emissions. For forests and woodlands the starting point 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.

The Exmoor National Park Authority has instigated a Carbon Neutral Exmoor programme which aims to transform Exmoor into a low carbon community. The programme includes an assessment of the current carbon balance of ENP and the identification of actions to achieve carbon neutrality by 2025. This report will help to identify and quantify the potential for new and existing woodlands to contribute to achieving this aim.

Footnote: There are generally considered to be six greenhouse gases (GHGs) contributing to climate change, all with different "global warming potential". OverallCO2 makes the largest contribution to global warming and GHG emissions are usually stated as "tonnes CO2 equivalent", shortened in this report to tCO2.

3. Scope of the Report

This report provides estimates of the following:

A. Existing woodlands

- Amount of carbon stored in above and below ground tree biomass
- Annual sequestration of carbon in above and below ground tree biomass
- Annual removal of carbon in harvested wood products
- Annual addition to carbon stored in manufactured wood products from current production
- Annual carbon gain (reduced carbon emissions) resulting from construction timber replacing higher embedded energy materials (material substitution)
- Annual carbon gain from the production and use of woodfuel, substituting for fossil fuels (energy substitution)
- Annual emissions of carbon in woodland management operations including timber haulage
- Carbon gains/losses through changes in carbon stores, material substitution and energy substitution, net of operational emissions, for 10 and 20 years ahead

B. Hedgerows and non-woodland trees

- Amount of carbon currently stored in hedgerows and non-woodland trees

C. New woodlands

- Potential carbon gains from 3 different types of new woodlands over a 100 year period, namely native broadleaf woodland, productive broadleaf woodland and conifer woodland

4. Data on woodlands in the Exmoor National Park

The primary source of data on the existing woodlands in ENP used in this report is the Forestry Commission (FC) National Inventory of Woodlands and Trees (NIWT) which has a reference date of 1999. The NIWT estimate of the area of woodland over 2 hectares in ENP was 8,331 hectares. There are clearly limitations in using inventory data which is almost 15 years old particularly with conifer woodlands where there will have been significant felling and restocking. In addition there will have been some new planting and woodland development through natural regeneration since 1999, although this will not yet have a major effect on carbon storage and sequestration. Interim data from the new National Forest Inventory (NFI) indicates that there is currently 9,300 hectares of woodland over 0.5 hectares in ENP, 12% more than in 1999. However a detailed breakdown of woodland composition is not yet available with the NFI: when this data does become available there is a case for revisiting the estimates in this report.

The area of woodland in ENP by species group and age from the NIWT (1999) data is shown in Appendix 1. In order to bring this data up to the present date it has been assumed that all the conifers planted before 1960 will by now have been clear felled, with the exception of some pre-1900 stands which are known to still exist. The felled areas are assumed to have been restocked with the same species. It has been assumed that there has been no clear felling of broadleaved woodland. The adjusted NIWT figures are shown in Table 1 below:

Table 1: Area of woodland over 2 hectares in ENP by species group and age class

Species Group	Age class (years)							Total
	0-20	21-40	41-60	61-80	81-110	111-150	Over 150	
Pines	180	68	56	0	0	34	0	338
Spruces	360	652	100	0	0	0	0	1112
Larch	213	112	416	0	0	0	0	741
DF/OCs	248	124	267	0	0	11	0	650
Total Conifers	1001	956	839	0	0	45	0	2841
Oak	0	8	511	504	247	1783	154	3207
SAB	0	106	743	224	151	33	0	1257
OBs	0	113	70	252	375	164	52	1026
Total Broadls	0	227	1324	980	773	1980	206	5490
Overall Total	1001	1183	2163	980	773	2025	206	8331

(All values are in hectares. DF = Douglas fir, OC = other conifers, SAB = sycamore/ash/birch, OB = other broadleaves.)

The total area of woodland over 2 hectares, using the 1999 data, is **8,331 hectares**, with 34% conifers and 66% broadleaves. Oak represents 38% of the total woodland area.

5. Carbon Stored in above and below ground tree biomass

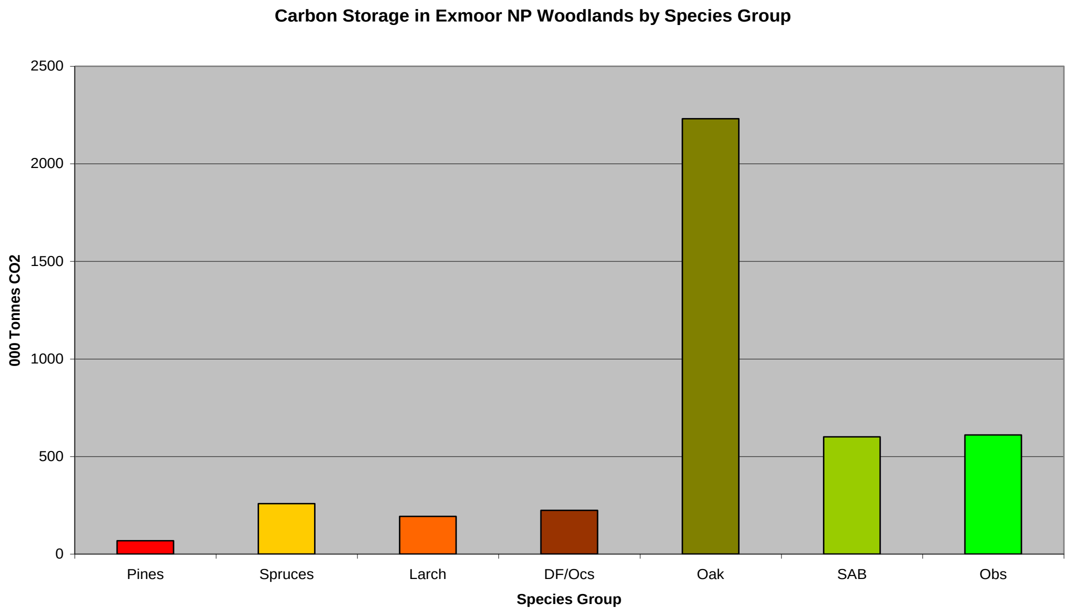
The estimates of the amount of carbon currently stored in above and below ground tree biomass in existing ENP woodlands are based on the NIWT 1999 data. They are shown by the main species groups and age classes in Appendix 2 and are summarised in Table 2 below. Notes on the assumptions on which the estimates are based are given in Appendix 2. The values for the amounts of carbon stored per hectare for a given species, yield class and age class are taken from FC Woodland Carbon Code Lookup Tables (Version 1.4) – see http://www.forestry.gov.uk/forestry/infd-8jue9t Note that these tables do not separately show above and below ground carbon.

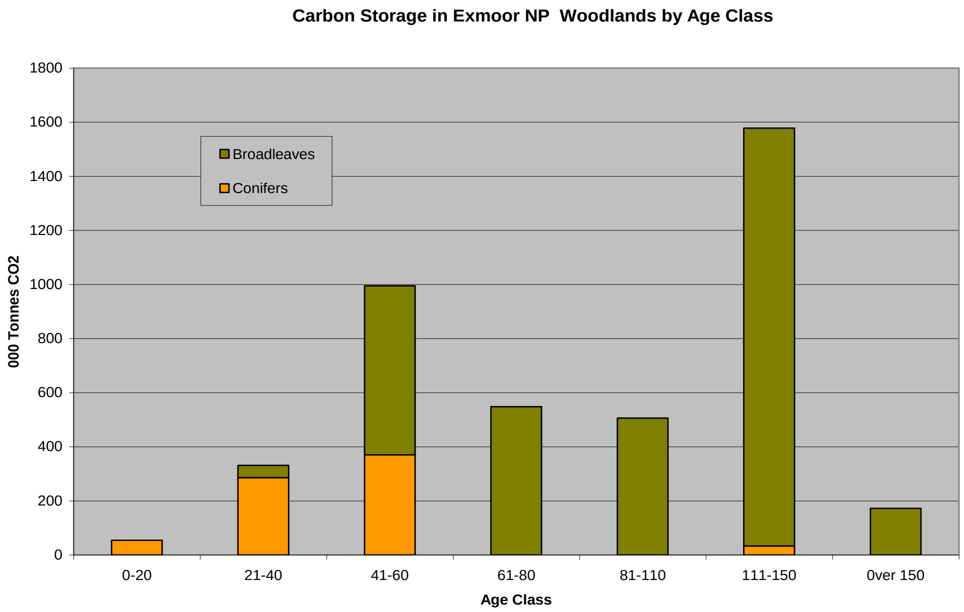
Table 2: Current carbon storage in tree biomass in ENP woodlands.

Woodland Type		Age class (years)							Total
		0-20	21-40	41-60	61-80	81-110	111-150	Over 150	
Conifer	Area (ha)	1001	956	839	0	0	45	0	2841
	Total C (tCO_2)	53626	286144	369586			32658		742014
Broad	Area (ha)	0	227	1324	980	773	1980	206	5490
	Total C (tCO_2)		45002	625382	548128	506116	1544806	172394	3441828
Total	Area (ha)	1001	1183	2163	980	773	2025	206	8331
	Total C (tCO_2)	53626	331146	994968	548128	506116	1577464	172394	4183842

The overall estimate is that there are currently **4,183,840 tonnes of CO_2** stored in above and below ground tree biomass in the existing ENP woodlands, of which 18% is in conifer woodlands and 82% is in broadleaved woodlands. The conifer woodlands currently store 261 tonnes CO_2 per hectare and the broadleaved woodlands 627 tonnes CO_2 per hectare. Just over 50% of the total carbon is stored in oak. It should be noted that, given the increase in woodland area between 1999 and 2013, the above figures will be an underestimate.

The values in Appendix 2 are shown in the charts below.





6. Carbon Sequestration in above and below ground tree biomass

The estimate of current annual sequestration in above and below ground tree biomass in existing ENP woodlands is shown in Appendix 3 and summarised in Table 3 below.

Table 3: Current annual carbon sequestration in tree biomass in ENP woodlands

Woodland Type		Age class (years)							Total
		0-20	21-40	41-60	61-80	81-110	111-150	Over 150	
Conifer	Area (ha)	1001	956	839	0	0	45	0	2841
	Total seq (tCO_2)	11240	9339	4574			45		25198
Broad	Area (ha)	0	227	1324	980	773	1980	206	5490
	Total seq (tCO_2)		3784	8616	4037	2542	3877	263	23119
Total	Area (ha)	1001	1183	2163	980	773	2025	206	8331
	Total seq (tCO_2)	11240	13123	13190	4037	2542	3922	263	48317

The overall estimate is that the existing woodlands in the ENP are currently sequestering **48,320 tonnes of CO_2 per annum**, of which 52% is in conifer woodlands and 48% is in broadleaved woodlands. The conifer woodlands are currently sequestering 8.9 tonnes of CO_2 per hectare annually and the broadleaved woodlands 4.2 tonnes of CO_2 per hectare annually.

7. Annual removal of carbon in harvested wood products

There are no reliable statistics on the amount of wood harvested annually from the woodlands in ENP. After discussion with various woodland managers it has been assumed that all conifer crops are thinned and clear felling takes place at age 60. For broadleaves the assumption is that 20% of the crops are thinned and that there is no clear felling. The estimates of annual removals of harvested wood products, both in terms of volume (m^3) and carbon (tonnes CO_2), are shown in Appendices 4 and 5. A summary of these appendices is shown in Table 4 below:

Table 4. Summary of annual removals in harvested wood products

Woodland type	Removals	
	Volume (m^3)	Carbon (tCO_2)
Conifer	32,741	23,330
Broadleaved	2,391	2,418
Totals	35,132	25,748

The figures above indicate that currently some **25,750 tonnes of CO_2** are removed from ENP woodlands each year. This amounts to 8.2 tonnes of CO_2 per hectare of conifers and 0.44 tonnes of CO_2 per hectare of broadleaves. The net annual sequestration in ENP woodlands can be estimated as 48,320 tonnes CO_2 (Table 3) less 25,750 tonnes CO2 (Table 4), i.e. **22,570 tonnes CO2.** This represents an annual net sequestration of 3.7 tonnes CO2 per hectare of conifers and 3.9 tonnes CO2 per hectare of broadleaves. Carbon removal in conifers is around 93% of annual sequestration, while carbon removal in broadleaves is around 10% of annual sequestration. These estimates should be treated with some caution as they are based on a number of significant assumptions. They could be improved by using the NFI data on woodland areas and composition when it becomes available, and by conducting a more detailed survey of annual harvesting programmes.

8. Annual addition to carbon stored in wood products

This estimate requires assumptions to be made on the wood products produced from the current harvesting programmes in the ENP. The following estimates of current product mix are the result of discussions with various woodland managers and sawmillers active in the area. Products which comprise a carbon store are taken here to be those with a life expectancy of at least 20 years. Note that at the end of a product's life there may still be a carbon gain if the product is recycled or used as a fuel. The product mix for conifer production is shown in Table 5 below.

Table 5. Product mix for conifer production (%)

Product	Diameter class		Comments
	7-18cm	Over 18cm	
Sawlog	30	80	Carbon stored
Wood based panels	20	20	Carbon stored
Round fencing	20	0	Carbon stored
Woodfuel	30	0	No carbon stored
Total %	100	100	

For the material going to a sawmill a 60% recovery is assumed, with 70 % of the production going to construction timber, 15% to sawn fencing, and 15% to pallets and packaging. It is assumed that of the 40% sawmill residues, 50% goes to wood based panels, 40% is used as fuel and 10% goes to mulch and animal bedding.

For broadleaves it is assumed that all material less than 18cm diameter goes to woodfuel and 80% of the material over 18cm diameter goes to sawmills with 20% to woodfuel. The assumed sawmill recovery is 60% with all the residues going to woodfuel. Half of the sawnwood output goes to furniture and half to construction, both of which are carbon stores.

The annual addition to the amount of carbon stored in wood products has been calculated from the annual volume of conifers and broadleaves harvested (Appendices 4 and 5) and the product mix and carbon storage assumptions above. The results are shown in Table 6 below.

Table 6. Annual addition to carbon stored in wood products

Woodland Type		Annual Production (m3)		Total addition to C store (tCO2)
		7-18cm	Over 18cm	
Conifer	Vol (m3)	11599	21142	
	% to C store	61	77	
	tCO2 to store	4670	12047	16717
Broadleaf	Vol (m3)	1208	1183	
	% to C store	0	48	
	tCO2 to store	0	579	579
Total		4670	12626	17296

The total addition to carbon stored in wood products is therefore estimated at **17,300 tonnes of CO2** per annum.

9. Annual carbon gain from material substitution

Using the annual production estimates in Appendices 4 and 5 and the product mix assumptions in Section 8 above, results in an estimate of some 8,565m3 of conifer and 284m3 of broadleaved timber going into construction use each year. A report by the International Institute for Environment and Development (2004) and other sources suggest that substituting a cubic metre of wood for other high embedded energy construction materials such as concrete and brick, saves between 0.7 and 1.0 tonnes CO2. In the UK where only around 25% of new houses are timber framed it seems reasonable to claim this potential substitution gain for construction timber. Using a figure of 0.85, midway between 0.7 and 1.0, produces an overall material substitution gain (additional to carbon storage in Section 7) from current ENP woodland production of **7,520 tonnes of CO2** per annum. It should be noted that this figure is dependant on a number of assumptions and should be regarded as at best a rough estimate. It also does not allow for the possibility that other products such as fencing, pallets, wood based panels and furniture may be substituting for non-wood products with higher embedded energy.

10. Annual carbon gain from woodfuel

The use of wood as a fuel, assuming that it comes from sustainably managed woodland, provides a carbon gain through direct substitution of fossil fuels. Using the annual production values in Appendices 4 and 5, and the product mix and sawmill recovery and residue use values in Section 8 above, results in an estimate of 6,743m3 of conifer and 1,832m3 of broadleaved wood going to woodfuel per annum. The FC publication "Woodfuel Meets the Challenge" indicates that conifers and broadleaves generate 5.0GJ and 6.3GJ of energy per m3 respectively (at 27% moisture content). Using these values and assuming that woodfuel is carbon neutral and is substituting for fossil based fuels releasing 356kg CO2 per MWh, the carbon gain is **2,210 tonnes of CO2** per annum from conifer woodfuel and **1,140 tonnes of CO2** per annum from broadleaved woodfuel.

11. Annual emissions of carbon in woodland management operations

The FC Woodland Carbon Code Look-up Tables provide values for emissions of carbon in thinning operations, although it is not clear exactly how these values have been derived. A study of carbon emissions from forest operations in Kielder Forest (Greig, Scottish Forestry 2010) indicates the following levels of emissions, mainly from vehicle fuel use:

- Harvesting operations 1.6 kg C per m3
- Timber haulage 1.4 kg C per m3
- Forest management operations 3.4 kg C per ha
- Management/operator travel 1.7 kg C per ha
- Road construction/maintenance 0.4 kg C per m3

It seems reasonable to apply these emission factors to the ENP conifer woodlands as the forest management operations are broadly similar. The totals from the above data are 3.4 kg carbon (12.5 kg CO2) per m3 for harvesting, roads and haulage and 5.1 kg carbon (18.7 kg CO2) per hectare for the other elements. Using these emission factors the total annual emission of carbon from the management of the conifer woodlands is 462 tonnes of CO2. Assuming that only 20% of the broadleaf woodland area is actively managed and using the 12.5 kg CO2/m3 the annual emissions for the broadleaved woodland is 50 tonnes of CO2. Total emissions for woodland management operations in the ENP are therefore estimated at **510 tonnes of CO2** per annum. The ratio of sequestration in tree biomass to emissions is around 95:1. It should be noted that these estimates do not include emissions from the manufacture of wood products.

12. A note on soil carbon

No attempt has been made in this report to calculate the quantity of carbon stored in the soil. There is very little data on soil carbon levels for different soil types under different types and ages of forest in the UK and any estimates would be very speculative. A report on carbon stores in Kielder Forest (Greig, Scottish Forestry 2010) indicates that soil carbon levels are likely to average between 520 and 700 tonnes of carbon per hectare. Using these values, the quantity of carbon stored in the ENP woodland soils would be between 1.05 and 1.4 times the quantity stored in the tree biomass. The amount of carbon stored in the soil can be reduced by forest operations which disturb significant volumes of soil, such as cultivation and de-stumping. On the other hand soil carbon levels tend to increase over time under woodland cover provided there is little soil disturbance.

13. Summary of carbon stores, sequestration, gains and emissions

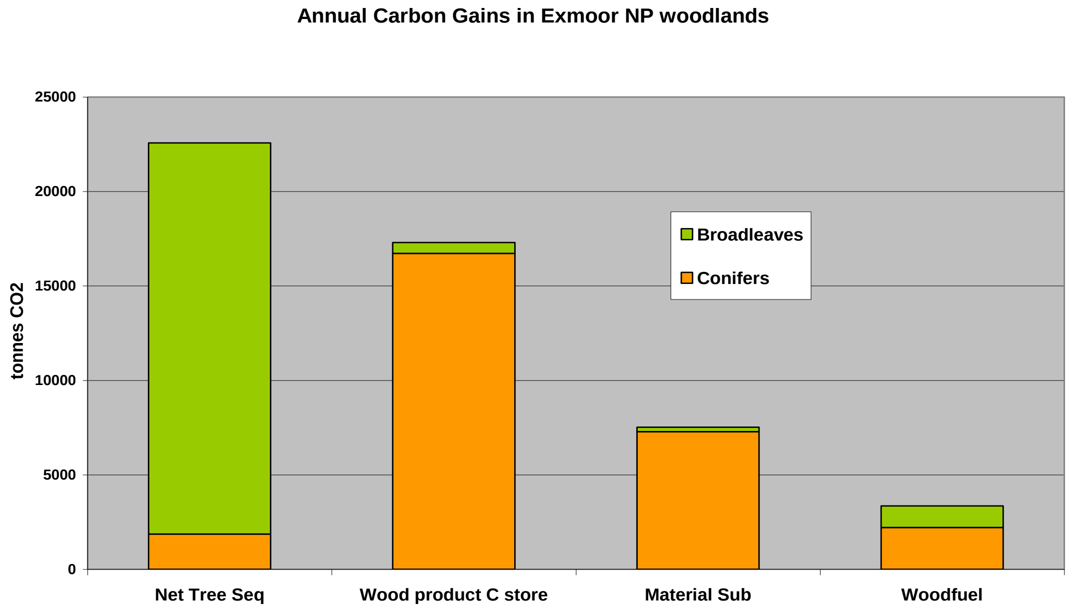
Table 7 below summarises the estimates provided in the preceding sections of this report as a woodland carbon current account.

Table 7: Summary annual carbon account for the ENP woodlands

Item	Conifers (tCO_2)	Broadleaves (tCO_2)	Total (tCO_2)	Notes
Area (ha)	2,841 ha	5,490 ha	8,331 ha	Table 1
1.Stored in tree biomass	742,010	3,441,830	4,183,840	Table 2
2.Annual sequestration	25,200	23,120	48,320	Table 3
3.Removed in HWP	23,330	2,420	25,750	Table 4
4.Added to WP CO_2 store	16,720	580	17,300	Table 6
5.Material subst. CO_2 gain	7,280	240	7,520	Section 9
6.Woodfuel CO_2 gain	2,210	1,140	3,350	Section 10
7.Operational emissions	460	50	510	Section 11
Net CO_2 gain/annum	27,620	22,610	50,230	
Net CO_2 gain/ha/annum	9.7	4.1	6.0	

Notes: HWP = harvested wood products, WP = wood products
Net CO_2 gain = 2 + 4 + 5 + 6 minus (3 + 7)

These values are shown in chart form below: note that Net Tree Sequestration is the annual sequestration in tree biomass less removals in harvested wood products.



The main source of carbon gain in broadleaves is sequestration in tree biomass whereas for conifers it is carbon storage in wood products and material substitution. This is because of the far higher levels of harvesting in conifer woodlands. Overall conifers are generating over twice as great a carbon gain on a per hectare basis.

14. Carbon gains over the next 10 and 20 years

Carbon gains over a period into the future can be estimated by summing:

- increase in carbon stored in tree biomass

- addition to carbon stored in wood products
- carbon gain through material substitution
- carbon gain through woodfuel
- minus operational carbon emissions

Ideally the estimates would be based on a reasonable understanding of the planned harvesting programmes over the next 10 and 20 years. With woodland properties where felling and restocking intentions are planned and mapped over the next 20 years in forest design plans, it would be possible to construct estimates in this way, although there is no certainty that the plans would be followed. The difficulty is compounded by the fact that NIWT is now almost 15 years old and the estimate of the current tree biomass carbon store is inevitably somewhat inaccurate. The NFI and associated production forecasts will provide an opportunity to significantly improve the estimates.

Given these difficulties the approach taken in this report has been to project forward the annual net sequestration rates set out in Table 7. Constructing the estimates in this way requires the assumption that annual sequestration, removals of harvested wood products and product mix remain as at present. This seems reasonable for broadleaved woodland where there is unlikely to be a substantial increase in active management (particularly clear felling) and the growth rates do not decline rapidly with age. The estimates for conifer woodland will be less robust as there is likely to be substantial clear felling over the next two decades. Noting these caveats the estimates are given in Table 8 below.

Table 8: Estimate of carbon gains over the next 10 and 20 years

	Woodland type		
	Conifer	Broadleaved	Total
Area (hectares)	2,841	5,490	8,331
Net CO2 gain (tCO2/ha/annum)	8.9	4.2	5.8
Net CO2 gain over 10 years (tCO2)	252,850	230,580	483,430
Net CO2 gain over 20 years (tCO2)	505,700	461,160	966,860

15. Carbon gains from bringing neglected woodland into management

It is apparent that nearly all the conifer woodlands in the Exmoor National Park are actively managed. However the majority of broadleaved woodlands are not currently being managed, at least in the sense of regular harvesting of wood products. The question arises as to the potential carbon gains that could accrue from bringing these “neglected” broadleaved woodlands into management.

Bringing neglected woodlands into management would result in increased carbon being stored in wood products and carbon gains through direct and indirect fossil fuel substitution. However this would be balanced by a lesser amount of carbon being stored in tree biomass, some carbon emissions from management operations and probably reduced carbon storage in the litter and soil. Given the number of uncertainties and the limitations of the FC models it would be unwise to attempt to quantify the carbon gain (or loss) without knowing more about the woodlands in question. A key factor would be the current stocking levels in neglected woodlands in the ENP: if the woodlands are understocked, it is more likely that bringing them into management would result in a carbon gain. A 2012 FC Research Report "Understanding the carbon and greenhouse gas balance of forests in Britain" concluded in relation to the carbon impacts of restoring neglected broadleaved woodland:

- It is often better to restore production in neglected broadleaf forests in the UK than to leave wood in the forests and meet needs for materials and bioenergy from non-wood sources
- Some scenarios are better than others
- The "best" scenarios generally involve using small roundwood and sawlogs as a source for materials and some sawlog and roundwood co-products, bark and branchwood as a source for bioenergy
- This conclusion is highly sensitive to assumptions about how management is restored in neglected broadleaf forests

A significant proportion of the broadleaved woodlands in ENP are overstood oak coppice, previously managed for tan bark and charcoal production. Table 9 below sets out the carbon gain implications for 4 different management scenarios over a 100 year period. It is assumed that the starting point for all 4 scenarios is a 100 year old YC 4 oak woodland with an above ground volume (to 7cm) of 250m3 per hectare. The calculations are based on FC Management Tables and Carbon Lookup Tables. The only product is woodfuel.

Table 9: Carbon gains from oak coppice management scenarios over 100 years

Scenario	Volume removed (m3/ha)	Woodfuel C gain (tCO2/ha)	Increase in tree biomass C (tCO2/ha)	Total C gain (tCO2/ha)
Do nothing	0	0	187	187
Thin	127	79	49	128
Coppice once	250	156	0	156
Coppice 3 times	457	283	-250	33

The figures indicate that the "do nothing" scenario is best in terms of carbon gains. However as stands become older growth decreases and eventually effectively ceases. Management regimes such as coppicing which result in continuing growth would in time result in greater carbon gain. There would be merit in recalculating the figures using actual stocking and growth values from a sample of stands of different ages in ENP.

There are of course other ecosystem services, aside from the potential to reduce net greenhouse gas emissions, which should be brought in to any assessment of the merits of bringing neglected woodlands into management. Many of the woodlands currently have high biodiversity values which might be impacted in either a positive or negative way. Introducing more management is likely to increase the structural diversity of woodlands and may make them more resilient to climate change. There is a case for further work, possibly looking at a few characteristic types of neglected woodlands in ENP, to assess the carbon and other impacts which would result from increased levels of management.

16. Hedgerows and non-woodland trees

Trees in hedgerows, and non-woodland trees are not covered by the Forestry Commission woodland inventories and a different approach was taken to estimate carbon storage in these trees. Aerial photography was used to calculate the length of mature hedgerows and the number of individual trees in 7 one kilometre squares in the Exmoor NP area. The 7 squares had been selected by ENPA staff to be representative of the range of farmed landscape types in the National Park. On site survey, carried out in January 2013, was then used to estimate the above and below ground tree biomass in a sample of trees the in the 7 squares. The methodology is described in Appendix 6. The estimated tree volumes and carbon storage from the 7 one kilometre squares is summarised in Table 10.

Table 10. Tree biomass and carbon storage in hedgerows and non-woodland trees

Kilometre Square	Hedgerows			Individual Trees			Total	
	Length (m)	Vol. (m3)	Carb. (tCO2)	No.	Vol. (m3)	Carb. (tCO2)	Vol. (m3)	Carb. (tCO2)
Kitnor	2193	4562	4562	9	6	6	4568	4568
Tivington	1003	1355	1057	35	301	305	1656	1362
Bury	2768	3104	3104	30	234	213	3338	3317
Whiterocks	1404	4050	4050	33	151	139	4201	4189
Wheatclose	405	370	370	19	287	292	657	662
Martinhoe	666	349	349	103	170	154	519	503
Leighland	1954	3565	3565	109	319	307	3884	3872
Totals	10393	17355	17057	338	1468	1416	18823	18473

Total carbon storage in hedgerow and individual trees in the 7 kilometre squares is estimated to be **18,470 tonnes of CO2.** Of this 92% is estimated to be in hedgerow trees.

The total area of farmed landscapes in the National Park is estimated at 383.7 square kilometres, so the 7 squares represent 1.82% of the farmed landscape. Assuming that the 7 kilometre squares are representative of ENP as a whole, the total amount of carbon stored in above and below ground tree biomass in hedgerow and individual trees is estimated to be **1,015,000 tonnes of CO2.** This compares with the amount stored in woodlands (Table 2) estimated to be **4,183,840 tonnes of CO2.** It should be noted that these estimates exclude carbon stored in woodlands less that 2 hectares in size which were not covered in the NIWT inventory.

17. New woodlands

The carbon gains over a 100 year period for 3 different woodland types have been calculated. The specification for the woodland types, considered to be appropriate to conditions in Exmoor National Park, are as follows:

A. Native (broadleaved) woodland – 50% oak YC 4
30% hazel/birch/rowan YC 4
20% shrubs and open ground

B. Productive broadleaf woodland – 25% oak YC 8
25% sycamore/ash/birch YC 10
25% beech YC 10
15% conifer YC 24 (from above)
10% open ground

C. Conifer woodland – 25% Sitka spruce YC 24
25% Douglas fir YC 24
25% Western red cedar YC 24
15% Grand fir YC 24
10% open ground

Excel spreadsheets and charts for these 3 models, and the assumptions underlying them, are provided in Appendix 7. The results are summarised in Table 11 below.

Table 11: Carbon gains for ENP woodland creation models

Element	Carbon gains after 100 years (tonnes CO2 per hectare)		
	Native Woodland	Productive Broadleaf	Conifer
Tree biomass	560.7	673.2	891.3
Wood product C store	0	100.5	165.6
Material substitution	0	98.7	229.0
Woodfuel	0	162.7	80.3
Total C gain	560.7	1035.1	1366.2
Emissions	0	8.5	15.5
Total net C gain	560.7	1026.6	1350.7

The overall carbon gain for the productive broadleaf model is 1.8 times that for the native woodland model, and the conifer model is 2.4 times that for the native woodland model over a 100 year period.

18. The wider context: GHG emissions in Exmoor National Park

A wider context for the potential for carbon storage and sequestration in woodlands in Exmoor National Park is set out in the 2010 document “Exmoor National Park Carbon Neutral Programme: Consultation”. This includes an estimate for GHG emissions within the ENP area of 351,772 tonnes CO_2e per annum, of which some 45% comes from agricultural emissions. There is a commitment in the ENP Management Plan (2007-2012) to deliver a target of zero net carbon emissions by 2025. The draft programme to deliver this target includes 180 hectares of new woodland planting each year.

The net carbon gain from the existing woodlands in ENP is estimated to be 50,230 tonnes CO_2 per annum, or 6.0 tonnes CO_2 per hectare (see Table 7). This equates to 14% of the total annual emissions within ENP. There is scope to improve the carbon performance of existing woodlands although it is beyond the remit of this report to estimate what a realistic target for the existing woodlands might be. The most obvious opportunity lies in bringing a higher proportion of the older broadleaved woodlands into productive management, particularly where they are significantly understocked (see Section 15 above).

The potential for new woodlands to contribute to the target is more straightforward. Assuming an even mix of the 3 woodland creation models (Table 8), a planting programme of 180 hectares per annum would generate net emission reductions of 1,760 tonnes of CO_2 per annum. If this programme was continued for 20 years the long term emissions reduction would amount to 35,280 tonnes of CO_2 per annum, some 10% of the current GHG emissions in the National Park. This excludes the carbon gains that would result from increased soil carbon levels (assuming that peaty soils were avoided) and a reduction in agricultural GHG emissions from the planted land.

16. Acknowledgements

The construction of this carbon account for the Exmoor National Park woodlands has depended on the considerable input of local knowledge and expertise from a number of woodland owners, contractors, sawmillers and other experts working in the area. In particular I would like to thank Graeme McVittie and Loren Eldred of the Exmoor National Park Authority, William Theed of Theed Forestry Estate, Nick Salter of the Forestry Commission, Graeme Smith of Crown Estates, Julian Gurney of the National Trust, Christopher Thomas-Everard, Bernard Dru, Dave Radford of Kleen Kutt, Mark Williams of Euroforest, Martin Bishop of A.J Charlton and Sons, Pontrilas Sawmill, and Dave Burd of BSW.

Sandy Greig
Sandwood Enterprise
August 2013

Appendix 1

NIWT (1999) data for Exmoor Woodlands: Areas by species and planting year

Species Group	Planting Year										
	After 91	81-90	71-80	61-70	51-60	41-50	21-40	01-20	1860-1900	Before 1860	Total
Pines	0	11	57	56	180	0	0	0	34	0	338
Spruces	94	323	329	100	230	36	0	0	0	0	1112
Larch	190	91	21	416	23	0	0	0	0	0	741
DF	112	80	0	267	136	0	0	0	0	0	595
OCs	0	44	0	0	0	0	0	0	11	0	55
Total Conifers	396	549	407	839	569	36	0	0	45	0	2841
Oak	0	8	0	0	511	303	235	213	1783	154	3207
SAB	0	16	90	523	220	224	23	128	33	0	1257
OBs	0	64	49	6	64	155	104	368	164	52	1026
Total Broads	0	88	139	529	795	682	362	709	1980	206	5490
Overall Total	396	637	546	1368	1364	718	362	709	2025	206	8331

All values are in hectares

Appendix 2

Current carbon storage in Exmoor NP Woodlands by species group and age class

Species Group		Age class (years)							Total
		0-20	21-40	41-60	61-80	81-110	111-150	Over 150	
Pines	Area (ha)	180	68	56	0	0	34	0	338
	C store/ha (tCO2)	22	240	421			703		
	Total C (tCO2)	3960	16320	23576			23902		67758
Spruces	Area (ha)	360	652	100	0	0	0	0	1112
	C store/ha (tCO2)	29	299	522					
	Total C (tCO2)	10440	194948	52200					257588
Larch	Area (ha)	213	112	416	0	0	0	0	741
	C store/ha (tCO2)	98	260	343					
	Total C (tCO2)	20874	29120	142688					192682
DF/OCs	Area (ha)	248	124	267	0	0	11	0	650
	C store/ha (tCO2)	74	369	566			796		
	Total C (tCO2)	18352	45756	151122			8756		223986
Total Conifers	Area (ha)	1001	956	839	0	0	45	0	2841
	Total C (tCO2)	53626	286144	369586			32658		742014
Oak	Area (ha)	0	8	511	504	247	1783	154	3207
	C store/ha (tCO2)		138	479	583	688	782	825	
	Total C (tCO2)		1104	244769	293832	169936	1394306	127050	2230997

SAB	Area (ha)	0	106	743	224	151	33	0	1257
	C store/ha (tCO_2)		299	471	521	555	560		
	Total C (tCO_2)		31694	349953	116704	83805	18480		600636
OBs	Area (ha)	0	113	70	252	375	164	52	1026
	C store/ha		108	438	546	673	805	872	
	Total C (tCO_2)		12204	30660	137592	252375	132020	45344	610195
Total Broadls	Area (ha)	0	227	1324	980	773	1980	206	5490
	Total C (tCO_2)		45002	625382	548128	506116	1544806	172394	3441828
Overall Total	Area (ha)	1001	1183	2163	980	773	2025	206	8331
	Total C (tCO_2)	53626	331146	994968	548128	506116	1577464	172394	4183842

Notes: 1. Spruce model is SS YC 16, thinned
2. Larch model is JL YC 12, thinned
3. Pine model is SP YC 12, thinned
4. DF/OC model is DF YC 16, thinned
5. Oak model is YC 4, 20% thinned
5. Sycamore/ash/birch (SAP) model is SAB YC 4, 20% thinned
6. Other broadleaves model is beech YC 4, 20% thinned
7. Area (ha) figures are net (NIWT) so no reduction made for open space, roads etc.
8. Values from the FC Carbon Lookup Tables in tonnes CO_2 equivalent.
9. Values include carbon stored in stems, branches, foliage and roots.
10. Carbon stored in soils is not included

Appendix 3

Current annual carbon sequestration in Exmoor NP woodlands

Species Group		Age class (years)							Total
		0-20	21-40	41-60	61-80	81-110	111-150	Over 150	
Pines	Area (ha)	180	68	56	0	0	34	0	338
	C seq/ha (tCO_2)	9.8	6.9	7.6			1.0		
	Total seq (tCO_2)	1764	469	426			34		2693
Spruces	Area (ha)	360	652	100	0	0	0	0	1112
	C seq/ha (tCO_2)	11.5	10.5	7.1					
	Total seq (tCO_2)	4140	6846	710					11696
Larch	Area (ha)	213	112	416	0	0	0	0	741
	C seq/ha (tCO_2)	9.1	6.0	3.9					
	Total seq (tCO_2)	1938	672	1622					4232
DF/OCs	Area (ha)	248	124	267	0	0	11	0	650
	C seq/ha (tCO_2)	13.7	10.9	6.8			1.0		
	Total seq (tCO_2)	3398	1352	1816			11		6577
Total Conifers	Area (ha)	1001	956	839	0	0	45	0	2841
	Total seq (tCO_2)	11240	9339	4574			45		25198
Oak	Area (ha)	0	8	511	504	247	1783	154	3207
	C seq/ha (tCO_2)		18.8	7.0	4.7	3.7	1.9	1.1	
	Total seq (tCO_2)		150	3577	2369	914	3388	169	10567

SAB	Area (ha) C seq/ha (tCO2) Total seq (tCO2)	0	106 14.4 1526	743 6.0 4458	224 1.6 358	151 1.1 166	33 0.4 13	0	1257 6521
OBs	Area (ha) C seq/ha Total seq (tCO2)	0	113 16.7 2108	70 8.3 581	252 5.2 1310	375 3.9 1462	164 2.9 476	52 1.8 94	1026 6031
Total Broadls	Area (ha) Total seq (tCO2)	0	227 3784	1324 8616	980 4037	773 2542	1980 3877	206 263	5490 23119
Overall Total	Area (ha) Total seq (tCO2)	1001 11240	1183 13123	2163 13190	980 4037	773 2542	2025 3922	206 263	8331 48317

Notes: 1. Spruce model is SS YC 16, thinned
2. Larch model is JL YC 12, thinned
3. Pine model is SP YC 12, thinned
4. DF/OC model is DF YC 16, thinned
5. Oak model is YC 4, 20% thinned
5. Sycamore/ash/birch (SAP) model is SAB YC 4, 20% thinned
6. Other broadleaves model is beech YC 4, 20% thinned
7. Area (ha) figures are net (NIWT) so no reduction made for open space, roads etc.
8. Values from the FC Carbon Lookup Tables in tonnes CO2 equivalent.
9. Values include carbon stored in stems, branches, foliage and roots.
10. Carbon stored in soils is not included

Appendix 4

Estimate of Annual Volume and CO2 removals in Harvested Wood Products: Conifers

Species Group		Age Class				Total Removals	
		0-20	21-40	41-60	111-150	m3	tCO2
Pines	Area (ha)	180	68	56	34		
	Vol<18cm	162	544	159	7	872	671
	Vol>18cm	0	27	1201	95	1323	1019
Spruce	Area (ha)	360	652	100			
	Vol<18cm	810	6390	350		7550	4568
	Vol>18cm	18	652	1890		2560	1549
Larch	Area (ha)	213	112	416			
	Vol<18cm	415	426	224		1065	820
	Vol>18cm	32	515	8195		8742	6731
DF/OCs	Area (ha)	248	124	267	11		
	Vol<18cm	694	1042	374	2	2112	1584
	Vol>18cm	0	347	8114	56	8517	6388
Totals	Area (ha)	1001	956	839	45		
	Vol<18cm	2081	8402	1107	9	11599	7643
	Vol>18cm	50	1541	19400	151	21142	15687
	Total	2131	9943	20507	160	32741	23330

All conifers 1st thinned at age 20, and every 5 years thereafter
All conifers felled at age 60
Assume even distribution of ages within each age class
Thinning and felling volumes from FC Booklet 34
Yield classes: spruce, DF and OCs = 16, pines and larch = 12
Carbon densities: spruce = 0.605 tCO2/m3
pines = 0.77 tCO2/m3
larch = 0.77 tCO2/m3
DF/OCs = 0.75 tCO2/m3

Appendix 5

Estimate of Annual Volume and CO2 removals in Harvested Wood Products: Broadleaves

Species Group		Age Class						Total Removals	
		21-40	41-60	61-80	81-110	111-150	Over 150	m3	tCO2
Oak	Area (ha)	8	511	504	247	1783	154		
	Vol<18cm	2	280	200	40	71	0	593	611
	Vol>18cm	0	0	80	100	639	36	855	881
SAB	Area (ha)	106	743	224	151	33			
	Vol<18cm	44	270	18	6	1		339	322
	Vol>18cm	0	60	27	12	2		101	96
OBs	Area (ha)	113	70	252	375	164	52		
	Vol<18cm	24	40	130	75	7	0	276	279
	Vol>18cm	0	0	10	132	65	20	227	229
Totals	Area (ha)	227	1324	980	773	1980	206		
	Vol<18cm	70	590	348	121	79	0	1208	1212
	Vol>18cm	0	60	117	244	706	56	1183	1206
	Total	70	650	465	365	785	56	2391	2418

20% of broadleaves thinned at age 30, and every 5 years thereafter. 80% non thin
No broadleaf felling
Assume even distribution of ages within each age class
Thinning and felling volumes from FC Booklet 34
All broadleaves YC 4
Carbon densities: oak = 1.03 tCO2/m3
SAB = 0.95 tCO2/m3
OBs = 1.01 tCO2/m3

Appendix 6

Methodology used to assess carbon storage in hedgerows and trees

1. In a study undertaken by Masters student Hannah Broscombe, 7 x 1 kilometre squares in different LCA Character areas in Exmoor National Park had been identified. The crown area of all the non woodland trees in each of these squares had been measured from recent aerial photography and ascribed to 1 of 5 size classes. The majority of the non-woodland trees were in hedgerows, as opposed to free standing individual trees.

2. Each of the 7 kilometre squares were visited between 7 and 11 January 2013. Measurements were made on a representative sample 20 metre hedgerow strips and on individual trees. The measurements taken were diameter breast height (dbh) and top height (using a clinometer): tree species was also noted.

3. It was noted that a significant number of trees identified in the mapping exercise described at 1 above should be described as woodland trees. This was particularly the case with small trees where the area was "scrubbing up". The definition of woodland used in the FC woodland inventories is that the tree species present on an area of land have the capacity to provide 20% canopy cover. Mapped data on the areas described as woodland in the National Forest Inventory (and dealt with as woodland in this study) is not yet available, so a subjective assessment was made on areas which were likely to have been described as woodland. Trees in these areas were not included in the count of individual trees. As the trees on these areas were generally small there would be little impact on the estimates of carbon storage.

4. Total length of hedgerow and the number of individual trees in each kilometre square were calculated from aerial photographs. The totals, and the length/number which were measured, were as follows:

Kilometer Square	Hedgerows		Individual Trees	
	Total length (m)	Sampled (m)	Total no.	Sampled
Kitnor Heath	2193	60	9	1
Bury	2768	60	35	4
Whiterocks Down	1404	60	30	5
Wheatclose Cross	405	40	33	6
Martinhoe	666	30	19	2
Tivington	1003	40	103	8
Leighland	1954	60	109	5
Totals	10393	350 (3.4%)	338	31 (6.5%)

5. Many of the trees measured multi-stemmed with forking at various heights from ground level up. All live stems over 12cm in diameter were measured at breast height. Some of the stems were growing at up to 90 degrees from vertical (i.e. they were nearly horizontal to the ground) but the top height of the tree or hedgerow was used in the volume calculation.

6. The volumes of each of the measured trees were estimated using the Forestry Commission Single Tree Tariff Tables. Timber height was taken to be 2 metres less than top height. The volumes given in the tariff tables were multiplied by 1.9 to allow for material less than 7cm diameter and below ground biomass

7. It should be recognised that the estimates of non-woodland tree numbers and volumes should be treated with considerable caution. The 7 kilometer squares represent some 1% of the National Park, the estimate of the length of hedgerow and individual trees involved some subjectivity, as did the choice of the sample trees to be measured. Finally the method of estimating trees volumes is not well suited to multi-stemmed open-grown trees.

8. The total area of farmed landscapes in the National Park is estimated at 383.7 square kilometres, so the 7 squares represent 1.82% of the farmed landscape.

Appendix 7

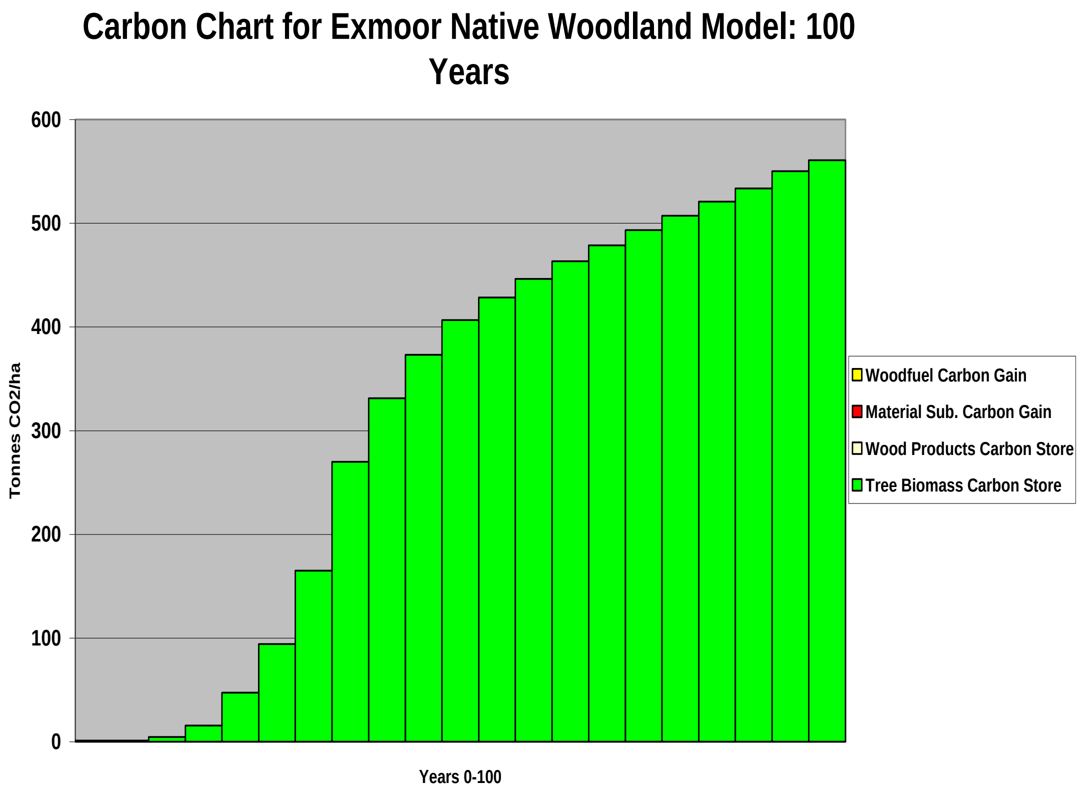
Potential carbon sequestration: Native woodland

Age (Years)	Tree Biomass Carbon Store	Wood Products Carbon Store	Material Sub. Carbon Gain (Cumulative)	Woodfuel Carbon Gain (Cumulative)	TOTAL Carbon Gain (Cumulative)	Carbon Emissions (Cumulative)
0	0	0	0	0	0	0
5	1.1	0	0	0	1.1	0
10	4.5	0	0	0	4.5	0
15	15.6	0	0	0	15.6	0
20	47.3	0	0	0	47.3	0
25	94.1	0	0	0	94.1	0
30	164.9	0	0	0	164.9	0
35	269.9	0	0	0	269.9	0
40	331.2	0	0	0	331.2	0
45	373.1	0	0	0	373.1	0
50	406.5	0	0	0	406.5	0
55	428.4	0	0	0	428.4	0
60	446.3	0	0	0	446.3	0
65	463.3	0	0	0	463.3	0
70	478.7	0	0	0	478.7	0
75	493.4	0	0	0	493.4	0
80	507.1	0	0	0	507.1	0
85	520.7	0	0	0	520.7	0
90	533.5	0	0	0	533.5	0
95	550.1	0	0	0	550.1	0
100	560.7	0	0	0	560.7	0

Native Woodland Model: 50% oak, 30% birch/hazel/rowan, 20% open ground
Oak is YC4, non thin
Birch/hazel/rowan is YC4, non thin

Carbon densities: oak = 1.03 tonnes CO_2 per m3, birch etc = 0.95 tonnes CO_2 per m3

All values are in tonnes CO_2 per hectare


Carbon Chart for Exmoor Native Woodland Model: 100 Years
600
500
400
300
200
100
0
Tonnes CO2/ha
Years 0-100
Woodfuel Carbon Gain
Material Sub. Carbon Gain
Wood Products Carbon Store
Tree Biomass Carbon Store

Appendix 7 cont.

Potential carbon sequestration: conifer woodland

Age (Years)	Tree Biomass Carbon Store	Wood Products Carbon Store	Material Sub. Carbon Gain (Cumulative)	Woodfuel Carbon Gain (Cumulative)	TOTAL Carbon Gain (Cumulative)	Carbon Emissions (Cumulative)
0	0	0	0	0	0	0
5	20.5	0	0	0	20.5	0
10	72.6	0	0	0	72.6	0
15		10.3	0.1	3.7	210.7	0.4
20	273.2	37.1	1.5	13.5	325.3	1.6
25	332.8	67.3	7.9	23.3	431.3	2.9
30	408.8	99.9	21.9	31.3	561.9	4.2
35	482.8	128.9	40.3	38.1	690.1	5.5
40	551	149.8	63	44.1	807.9	6.8
45	591.4	162.9	84.4	49.3	888	8
50	633.3	165.5	103.6	53.7	956.1	9
55	672.5	166.1	120.8	57.6	1017	9.9
60	711.1	167.4	136.2	60.9	1075.6	10.7
65	746.3	169.4	150.3	64	1130	11.4
70	777.4	172.2	163.4	66.8	1179.8	12.1
75	806.3	174	175.7	69.4	1225.4	12.7
80	829.2	173.6	187.4	71.8	1262	13.3
85	849.1	171.8	198.6	74.1	1293.6	13.9
90	865.9	169.3	209.1	76.2	1320.5	14.4
95	879.7	166.9	219.2	78.3	1344.1	14.9
100	891.3	165.6	229	80.3	1366.2	15.5

Conifer model: 25% Douglas fir, 25% Sitka spruce, 20% Western red cedar, 15% Grand fir, 5% broadleaf, 10% open ground

All conifers are YC 24, selective thin every 5 years

Broadleaf is from the productive broadleaf model, see sheet 3

Carbon densities: DF = 0.75 tonnes CO2 per m3, SS = 0.605 tonnes C per m3, WRC = 0.57 tonnes CO2 per m3, GF = 0.55 tonnes CO2 per m3

Products for 7-18cm conifer material: 20% wood based panels, 30% woodfuel, 20% round fencing, 30% to sawmills.
- of this 30%, half to pallets and packaging, half to fencing

All 18cm+ material to sawmill with 60% sawmill recovery. Sawn wood 70% to construction, 15% to pallets/packaging, 15% to fencing

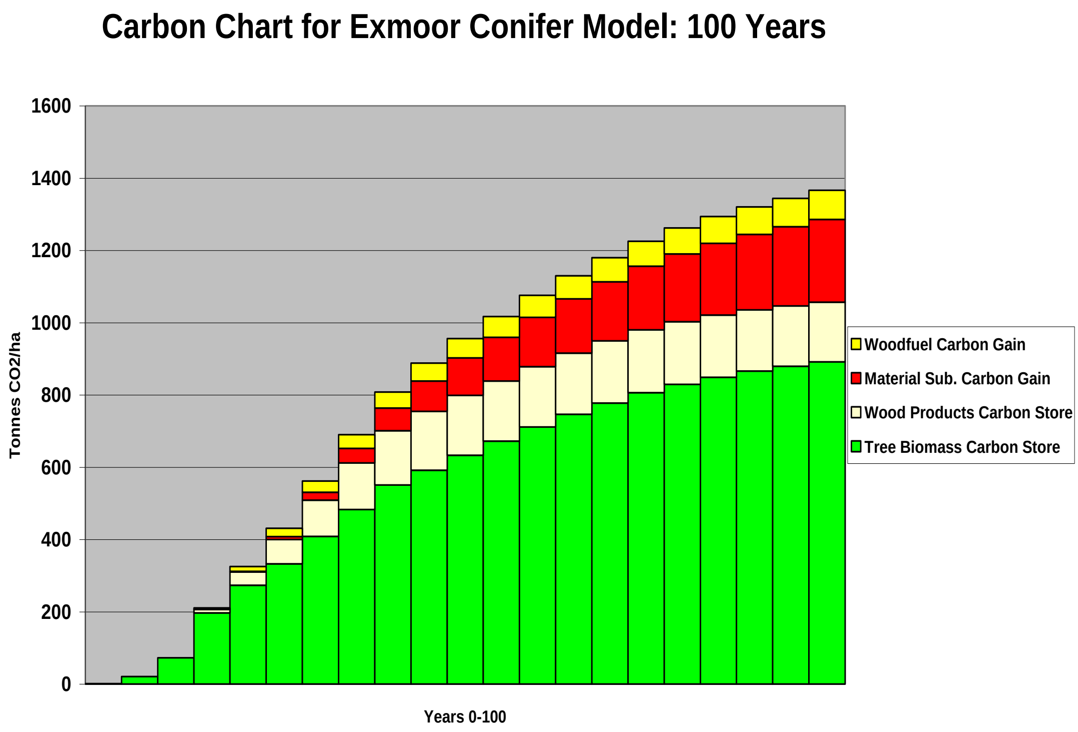
Assumed carbon storage: construction timber - no decay for 49 years, 50% decay at year 50, balance decays at year 90
: pulp, woodfuel, packaging and pallets and mulch/bedding - no carbon storage
: fencing - no decay for 19 years, 50% decay at year 20, balance decays at year 30
: wood based panels - no decay for 19 years, 50% decay at year 20, balance decays at year 30

Material substitution value of 0.85 tonnes CO2 per m3 of sawn product (only for construction timber)

Woodfuel carbon gain assumptions: conifer woodfuel generating 5.0 GJ/m3, saving 495kg CO2 emissions from fossil fuels per m3

Sawmill residues: 50% to wood based panels, 40% to woodfuel, 10% to mulch/bedding

Emission values based on 18kg CO2 per m3 harvested
All values are in tonnes CO2 per hectare


Carbon Chart for Exmoor Conifer Model: 100 Years
1600
1400
1200
1000
800
600
400
200
0
Tonnes CO2/ha
Years 0-100
Woodfuel Carbon Gain
Material Sub. Carbon Gain
Wood Products Carbon Store
Tree Biomass Carbon Store

Potential carbon sequestration: productive broadleaf woodland

Age (Years)	Tree Biomass Carbon Store	Wood Products Carbon Store	Material Sub. Carbon Gain (Cumulative)	Woodfuel Carbon Gain (Cumulative)	TOTAL Carbon Gain (Cumulative)	Carbon Emissions (Cumulative)
0	0	0	0	0	0	0
5	8.4	0	0	0	8.4	0
10	36.9	0	0	0	36.9	0
15	118.1	1.5	0	5.5	125.1	0.2
20	221.6	5.6	0.2	13.2	240.6	0.6
25	303.1	10.9	1.9	27.8	343.7	1.2
30	355.7	17.9	5.8	42.5	421.9	1.8
35	394.4	24.9	10.8	56.4	486.5	2.4
40	438.2	31.3	17	69.8	556.3	3
45	477	36.2	22.7	82.7	618.6	3.6
50	508.5	40.2	28.6	93.2	670.5	4.1
55	537.4	45.8	35.8	103.2	722.2	4.6
60	564.1	51.3	42.7	111.3	769.4	5.1
65	585	57.6	49.8	118.8	811.2	5.5
70	606	64.2	57.2	125.9	853.3	5.9
75	624.4	70.9	64.5	132.5	892.3	6.4
80	636.9	77.3	73.5	139.1	926.8	6.8
85	648.7	83.3	78.7	145.1	955.8	7.2
90	659.4	89.2	85.7	151.4	985.7	7.6
95	668.9	94.2	92.2	157.2	1012.5	8
100	673.2	100.5	98.7	162.7	1035.1	8.4

Productive Broadleaf Model: 25% oak, 25% sycamore/ash/birch, 25% beech, 15% conifer, 10% open ground

Oak is YC 8, other broadleaves are YC 10, thin every 5 years for all

Conifers are as per the conifer model (Sheet 2), all YC 24

Carbon densities: oak = 1.03 tonnes CO2 per m3, SAB = 0.95 tonnes CO2 per m3, beech = 1.0 tonnes CO2 per m3

Products for 7-18 cm braodleaf material: all to woodfuel

Products for over 18cm broadleaf material: 80% to sawlog, 20% to woodfuel

Sawmill has 60% recovery, all residues to woodfuel

All sawn output to constuction (80%), furniture and fencing

Assumed carbon storage: all sawn output has at least 70 years product life. No carbon storage with woodfuel

Material substitution value of 0.85 tonnes CO_2 per m3 of sawn product (construction only)

Woodfuel carbon gain assumptions: broadleaf woodfuel generating 6.3 GJ/m3 saving 623 kg CO_2 per m3

Emission values based on 18 kg CO_2 per m3 harvested

All values are in tonnes CO_2 per hectare