SANDWOOD ENTERPRISE

Report for Cumbria Woodlands

A Carbon Account for the Woodlands in the Lake District National Park

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A Carbon Account for the Woodlands in the Lake District National Park

Executive Summary

1. The Forestry Commission National Woodland Inventory (1999) shows the area of woodland over 2 hectares in the Lake District National Park as 28, 412 hectares. Of this 49% is conifer and 51 % is broadleaved. Using the inventory data the following estimates of carbon storage, sequestration and emissions have been developed:

- **12,591,000 tonnes of CO2 are currently stored in the woodlands in the National Park, of which 41% is in conifers and 59% in broadleaves.**
- **Current sequestration in tree biomass amounts to 159,600 tonnes of CO2 per annum, of which 65% is in conifers and 35% in broadleaves.**
- **62,100 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.**
- **35,600 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 11,700 tonnes and 21,500 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 164,750 tonnes of CO2 per annum. Of this 66% comes from conifers and 34% from broadleaves.**

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 – 880 tonnes CO2**
- **Native broadleaf – 440 tonnes CO2**
- **Mixed (50/50) – 660 tonnes CO2**

3. An improvement in the carbon performance of existing woodlands in the National Park of 1% per annum would represent 7% of the National Park emissions reduction target of 23,000 tonnes of CO2.

4. A planting programme of 350 hectares per annum (mixed woodland model) would contribute 2,300 tonnes of CO2 per annum (10%) towards the National Park emissions reduction target.

A Carbon Account for the Woodlands in the Lake District 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 the Lake District National Park (LDNP). The report was commissioned by Cumbria Woodlands to provide a clearer understanding of amounts of carbon currently stored in LDNP woodlands and the actual and potential role of existing and new woodlands in mitigating climate change through a reduction in net carbon emissions. The work was 50% funded by the European Social Fund and part funded by the Lake District National Park Sustainable Development Fund.

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.

This report provides estimates of the following for the existing LDNP 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**

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.

- **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**

The report also looks at the potential carbon gains from 3 different woodland creation models over a 100 year period.

3. Data on woodlands in the Lake District National Park

The primary source of data on the woodlands in the LDNP used in this report is the Forestry Commission's (FC) National Inventory of Woodlands and Trees (NIWT) which has a reference date of 1999. NIWT provides estimates of the area and composition of woodlands of over 2 hectares. There are clearly limitations in using inventory data which is over 10 years old particularly with conifer woodlands where there will have been significant felling and restocking. Updated inventory data should be available by the end of 2012 and there is a case for revisiting this report in, say, 12 months time.
The area of woodland in the LDNP by forest type and ownership is stated (NIWT 1999) as follows:

Table 1: Area of woodland over 2 hectares in the LDNP

Forest Type	Forestry Commission		Other		All Ownerships	
	ha	%	ha	%	ha	%
Conifer	6,372	68.2	4,973	26.1	11,346	39.9
Broadleaved	1,458	15.6	10,424	54.7	11,882	41.8
Mixed	616	6.6	1,686	8.8	2,302	8.1
Coppice	0	0	86	0.5	86	0.3
Windblow	89	1.0	17	0.1	106	0.4
Felled	392	4.2	150	0.8	542	1.9
Open space	415	4.4	1,732	9.1	2,147	7.6
Total	9,343	100	19,069	100	28,412	100

The carbon account estimates in this report exclude coppice woodlands (86ha) and woodlands less than 2 hectares. The areas (hectares) of conifer and broadleaved high forest used in generating the carbon account exclude windblow, felled and open space.

4. 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 LDNP woodlands are based on the NIWT 1999 data. They are shown by the main species groups and planting year classes in Appendix 1 and are summarised in Table 2 below. Notes on the assumptions on which the estimates are based are given in Appendix 1. The values for the amounts of carbon stored per hectare for a given species, yield class and 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: Summary of carbon storage in tree biomass in LDNP woodlands.

Woodland Type		Planting Year Class									Totals
		1991-1999	1981-1990	1971-1980	1961-1970	1951-1960	1941-1950	1931-1940	1921-1930	Pre-1921	
Spruce	Area (ha)	1033	434	1157	1174	1558	717	437	18	175	6,701
	Total C store (tCO2)	52683	121520	458172	656266	779000	398652	260889	11268	114275	2,852,725
Larch	Area (ha)	30	192	95	401	916	388	518	257	391	3,189
	Total C store (tCO2)	3510	65472	36480	182455	342584	157916	222222	114108	181033	1,305,780
Other Cons	Area (ha)	144	163	225	226	353	427	399	208	543	2,688
	Total C store (tCO2)	25992	24124	60975	82490	119667	163968	168378	93392	263898	1,002,884
Ash/ Syc/ Birch	Area (ha)	73	162	174	194	1025	1134	912	841	402	4,917
	Total C store (tCO2)	4234	39042	65424	89240	505325	586278	480624	451617	223512	2,445,296
Oak	Area (ha)	62	46	0	36	172	541	441	391	3742	5,432
	Total C store (tCO2)	310	1978		16920	88512	304540	269555	255323	2630626	3,567,764
Other Bdls	Area (ha)	38	36	135	231	517	511	337	364	540	2,709
	Total C store (tCO2)	342	1764	37800	98406	235235	259077	189731	223860	370440	1,416,655
Totals	Area (ha)	1380	1033	1786	2262	4541	3718	3044	2079	5793	25,636
	Total C store (tCO2)										12,591,104

The overall estimate is that there is currently 12,591,104 tonnes of CO2 stored in tree biomass in the existing LDNP woodlands, of which 41% is in conifer woodlands and 59% is in broadleaved woodlands. The conifer woodlands currently store 410 tonnes CO2 per hectare and the broadleaved woodlands 568 tonnes CO2 per hectare.

The values in Table 2 are shown in Charts 1 and 2 below.

Chart 1: Carbon stored in tree biomass shown by species group

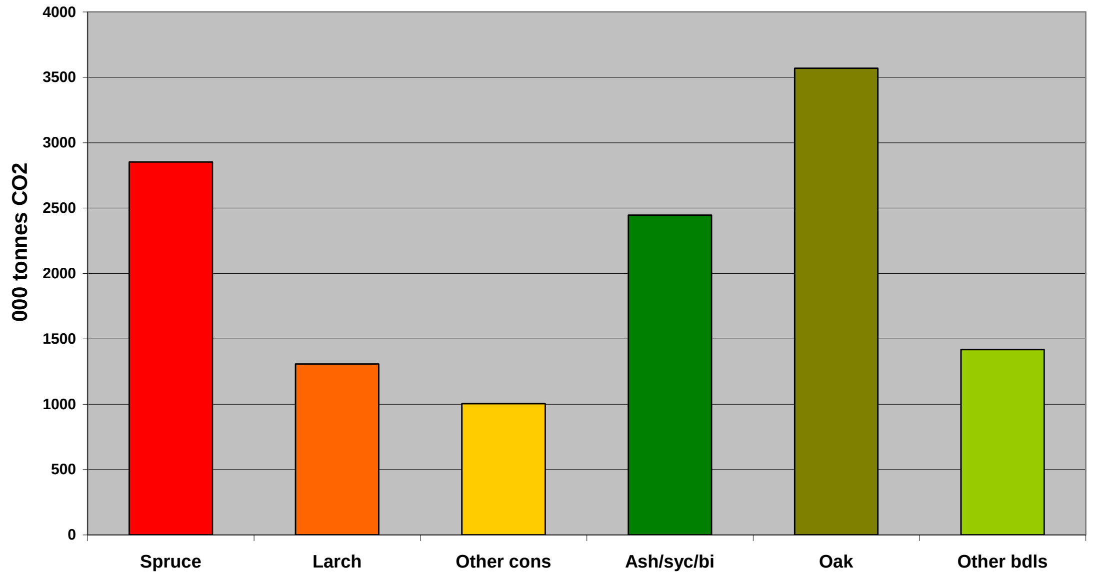
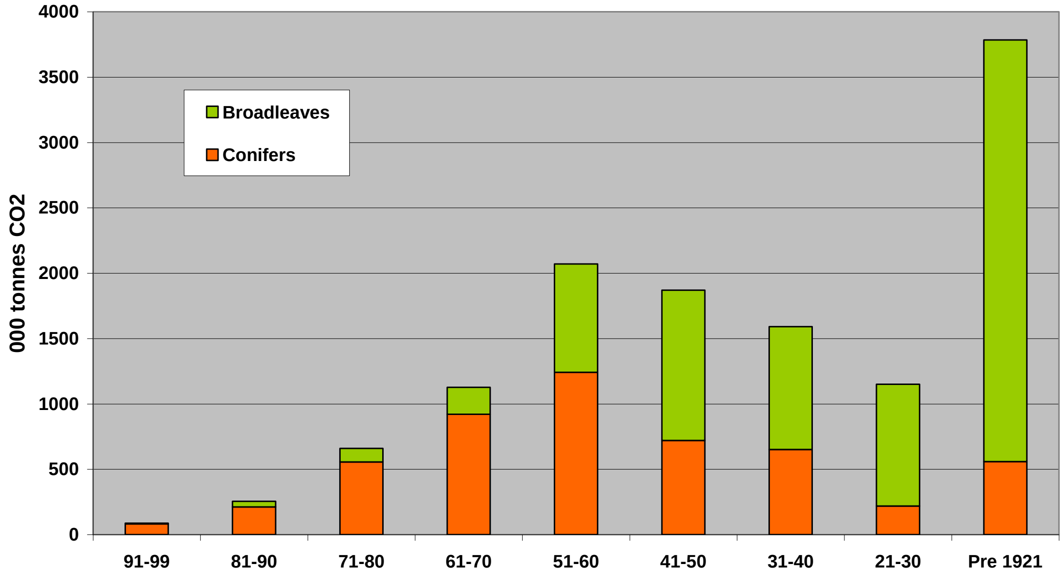


Chart 2: Carbon stored in tree biomass shown by planting year class



5. Carbon Sequestration in above and below ground tree biomass

The estimate of current annual sequestration in above and below ground tree biomass in existing LDNP woodlands is shown in Appendix 2 and summarised in Table 3 below.

Table 3: Summary of current annual sequestration in tree biomass.

Woodland Type		Planting Year Class									Totals
		1991-1999	1981-1990	1971-1980	1961-1970	1951-1960	1941-1950	1931-1940	1921-1930	Pre-1921	
Spruce	Area (ha)	1033	434	1157	1174	1558	717	437	18	175	6,701
	Total Seq (tCO_2)	20350	7855	18165	15027	9504	3011	1573	40	210	75,735
Larch	Area (ha)	30	192	95	401	916	388	518	25	391	3,189
	Total Seq (tCO_2)	843	2995	712	2246	3206	1086	777	360	391	12,616
Other Cons	Area (ha)	144	163	225	226	353	427	399	208	543	2,688
	Total Seq (tCO_2)	950	4173	2385	1718	1659	1708	1077	520	923	15,113
Ash/ Syc/ Birch	Area (ha)	73	162	174	194	1025	1134	912	841	402	4,917
	Total Seq (tCO_2)	1387	2527	1583	1727	2972	1814	1277	925	80	14,292
Oak	Area (ha)	62	46	0	36	172	541	441	391	3742	5,432
	Total Seq (tCO_2)	112	874		288	929	2867	2029	1759	15342	24,200
Other Bdls	Area (ha)	38	36	135	231	517	511	337	364	540	2,709
	Total Seq (tCO_2)	57	526	2605	2402	2895	2862	1887	1929	2484	17,647
Totals	Area (ha)	1380	1033	1786	2262	4541	3718	3044	2079	5793	25,636
	Total Seq (tCO_2)	23699	18950	25450	23408	21165	13348	8620	5533	19430	159,603

The overall estimate is that the existing woodlands in the LDNP are currently sequestering 159,603 tonnes of CO_2 per annum, of which 65% is in conifer woodlands and 35% is in broadleaved woodlands. The conifer woodlands are currently sequestering 8.2 tonnes CO_2 per hectare and the broadleaved woodlands 4.3 tonnes CO_2 per hectare.

6. Annual removal of carbon in harvested wood products

There are no reliable statistics on the amount of wood harvested annually in the woodlands in the LDNP. The FC have annual production forecasts for geographic areas (including the LDNP) and these tend to be reasonably accurate although planned programmes can change due to windblow and disease. For conifers this report uses the FC forecasts (FC have 56% of the conifers in the LDNP) applied pro

rata to other (non-FC) woodland. For broadleaves a different approach has been adopted: the assumption has been made, after discussion with various woodland managers, that harvesting (thinning) does not take place in woodlands younger than 50 and only 20% of the older woodland are thinned. The estimates and the assumptions made are in Appendix 3.

A summary of the estimates in Appendix 3 are shown in Table 4 below.

Table 4. Summary of annual removals of carbon in harvested wood products

Woodland type	Carbon removal (tCO2)		Total
	<18cm	Over 18cm	
Conifer	21,873	35,385	57,258
Broadleaved	2,452	2,389	4,841
Total (tCO2)	15,242	25,127	62,099

The figures above indicate that some 4.5 tonnes of CO2 per hectare of conifers and 0.4 tonnes of CO2 per hectare of broadleaves are removed in harvested wood products annually. The net annual sequestration in LDNP woodlands can be estimated as 159,603 tonnes CO2 (Table 3) less 62,099 tonnes CO2 (Table 4), i.e. 97,504 tonnes CO2. This equates to an annual net sequestration of 3.7 tonnes CO2 per hectare of conifers and 3.9 tonnes CO2 per hectare of broadleaves.

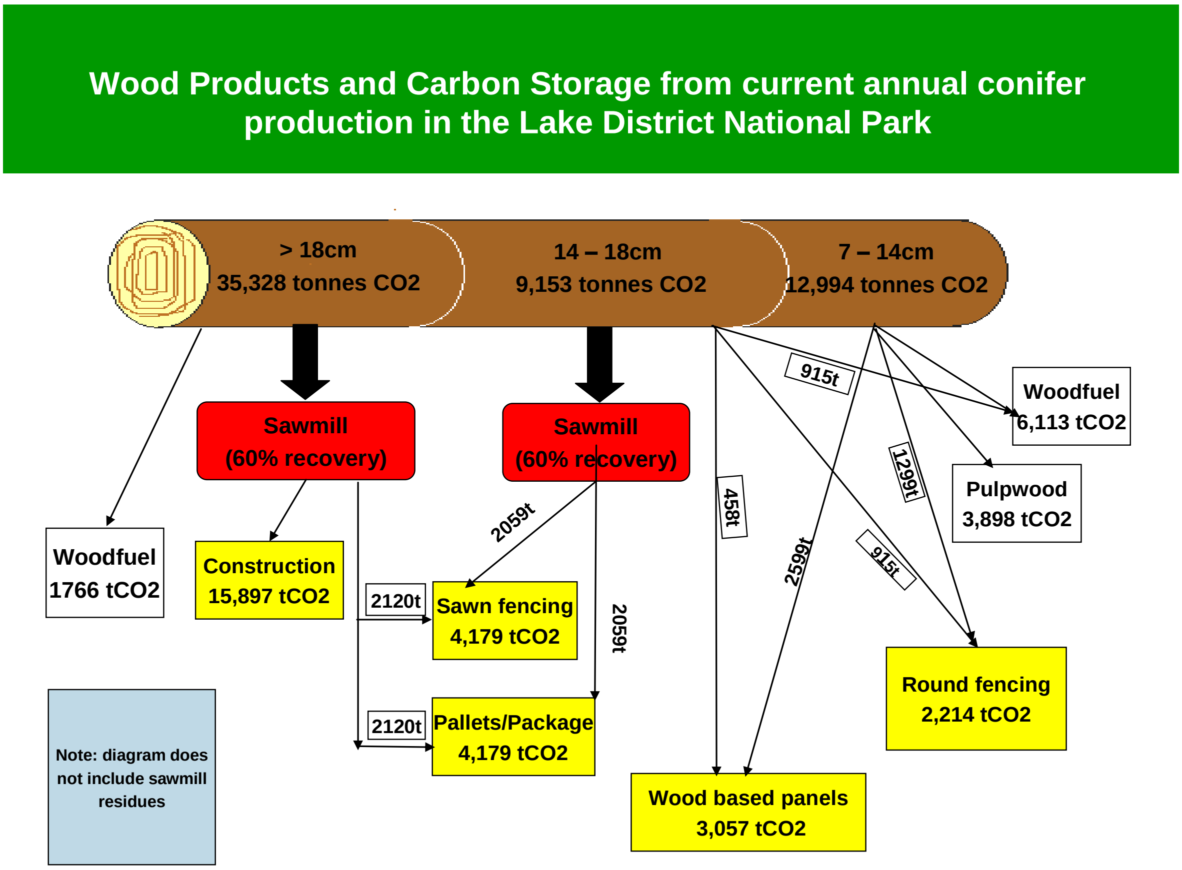
7. Annual addition to carbon stored in wood products

This estimate requires assumptions to be made on the wood products produced from the current harvesting programmes in the LDNP. The following estimates of current product mix are the result of discussions with various woodland managers and sawmillers active in the area.

Table 5. Product mix for conifer production

Product	Product % by size class			Comments
	7-14cm	14-18cm	Over 18cm	
Pulpwood	30	0	0	No carbon storage
Wood based panels	20	5	0	Carbon stored
Round fencing	10	10	0	Carbon stored
Woodfuel	40	10	5	No carbon storage
Sawmill	0	75	95	See below
Total %	100	100	100	

The amounts of carbon removed in conifer harvested wood products and the amounts going to the various wood products (shown in Tables 4 and 5) are illustrated in the diagram below:



For the 14-18cm material going to a sawmill a 60% recovery is assumed with 50 % of the production going to pallets and packaging and 50% to fencing, both of which are considered to be carbon stores. For the over 18cm material going to a sawmill a 60% recovery is assumed with 80% of the production going to construction timber and 20% to pallets, packaging and fencing, all of which are considered to be carbon stores. It is assumed that of the sawmill residues, 10% goes to compost/mulch, 30% to pulp chips, 30% to wood based panels and 30% to woodfuel. Of these only the 30% going to wood based panels is considered to be a carbon store.

For broadleaves it is assumed that all material under 18cm diameter goes to woodfuel and all material 18cm diameter and over goes to sawmills. 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 (Appendix 3) 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 CO2 store
		7-14cm	14-18cm	Over 18cm	
Conifer	Vol (m3)	19839	13974	53936	
	% to C store	30%	69%	68%	
	tCO2 to store	3898	6316	23980	34,194
Broadleaf	Vol (m3)	2523		2357	
	% to C store	0		59%	
	tCO2 to store	0		1400	1,400
Total					35,594

The total addition to carbon stored in wood products is therefore estimated at 35,594 tonnes of CO2 per annum.

8. Annual carbon gain from material substitution

Using the annual production values in Appendix 3 and the product mix assumptions in Section 7 above, results in an estimate of some 24,590m3 of conifer and 710m3 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 by substituting a cubic metre of wood for other high embedded energy construction materials such as concrete and brick, a saving of between 0.7 and 1.0 tonnes CO2 results. 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 produces an overall material substitution gain (additional to carbon storage in Section7) from current LDNP woodland production of 21,505 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.

9. 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 Appendix 3 and the product mix and sawmill recovery and residue use values in Section 7 above results in an estimate of some 19,257m3 of conifer and 3,545m3 of broadleaved wood going to woodfuel. The FC publication "Woodfuel Meets the Challenge" indicates that conifer 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 9532 tonnes CO2 per annum from conifer woodfuel and 2208 tonnes CO2 per annum from broadleaved woodfuel.

10. 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 recent 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 LDNP 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 1326 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 55 tonnes of CO2. Total emissions for woodland management operations in the LDNP are therefore estimated at 1411 tonnes of CO2 per annum. The ratio of sequestration in tree biomass to emissions is around 115:1. It should be noted that these estimates do not include emissions from the manufacture of wood products.

11. 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 recent report on carbon stores in Kielder Forest (Greig, Scottish Forestry 2010) indicates that soil carbon levels are likely to average between 143 and 190 tonnes of carbon per hectare. Using these values, the quantity of carbon stored in the LDNP woodland soils would be between 1.2 and 1.6 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.

12. 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 carbon account for the LDNP woodlands

Item	Conifers (tCO2)	Broadleaves (tCO2)	Total (tCO2)	Notes
Area (ha)	12,578 ha	13,058 ha	25,636 ha	Table 2
1.Stored in tree biomass	5,161,389	7,429,715	12,591,104	Table 2
2.Annual sequestration	103,464	56,139	159,603	Table 3
3.Removed in HWP	57,258	4,841	62,099	Table 4
4.Added to WP C store	34,194	1,400	35,594	Table 6
5.Material subst. C gain	20,902	603	21,505	Section 8
6.Woodfuel C gain	9,352	2,208	11,560	Section 9
7.Operational emissions	1,356	55	1,411	Section 10
Total net C gain	109,298	55,454	164,752	
Net C gain per ha	8.7	4.25	6.4	

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

13. 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 (direct substitution)**
- **minus operational carbon emissions**

These are considered in turn below.

13.1. Increase in carbon stored in tree biomass

The most obvious way to derive this value is to estimate the tree biomass carbon store in 10 and 20 years time and subtract the current estimate for the carbon store. However this requires a good understanding of age and species composition of the woodlands into the future. With FC woodlands, where felling and restocking intentions are planned and mapped over the next 20 years in Forest Design Plans, this would be provide a reasonably accurate estimate but here the FC only manage around 33% of the woodland area. The difficulty is compounded by the fact that NIWT is now 13 years old and the estimate of the current tree biomass carbon store is inevitably somewhat inaccurate. The 2012 NIWT 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 described in Section 6. Constructing the estimates in this way requires the assumption that current annual sequestration and current removals of harvested wood products remain at present levels. This seems a reasonable assumption for broadleaved woodland where there is unlikely

to be a substantial increase in active management (particularly clearfelling) and the growth rates do not decline rapidly with age. The estimates for conifer woodland will be less robust although the forecasts for the FC managed conifer woodland (56% of the total) indicate a relatively steady clearfelling programme and overall forecast of production over the next 20 years. Noting these caveats the estimates are given in Table 8 below.

Table 8: Estimate of increase in carbon stored in tree biomass

	Woodland type		
	Conifer	Broadleaved	All
Area (hectares)	12,578	13,058	25,636
Net seq. (tCO_2/ha/annum)	3.7	3.9	
Total net seq./annum (tCO_2)	46,538	50,926	97,464
Net seq. over 10 years (tCO_2)	465,380	509,260	974,640
Net seq. over 20 years (tCO_2)	930,760	1,018,520	1,949,280

13.2. Addition to carbon stored in wood products

Given the limitations of the data, see 13.1 above, it has been assumed that current levels of production and the current product mix is maintained over the 20 year period. The following assumptions have been made about product life:

Wood product	Product life assumptions
Construction timber	No product loss within 20 years
Round fencing	50% loss after 20 years, 100% after 30 years
Sawn fencing	50% loss after 20 years, 100% after 30 years
Pallets/packaging	100% loss after 2 years
Wood based panels	50% loss after 20 years, 100% after 30 years
Pulpwood	No carbon storage
Woodfuel	No carbon storage
Furniture (broadleaf only)	No product loss within 20 years

Note that these assumptions do not take into account the use of products as fuel at the end of their life or the potential carbon storage of wood products in land fill. Using the annual outturn of wood products in Section 7 and the product life assumptions above the estimated addition to the wood product carbon store is as follows:

Table 9: Addition to the wood product carbon store after 10 and 20 years

Period	Woodland type		
	Conifer	Broadleaved	All
Addition to store after 10 years (tCO2)	310,340	14,000	324,340
Addition to store after 20 years (tCO2)	612,320	28,000	640,320

13.3. Carbon gain through material substitution

Assuming that the current levels of production and the current product mix is maintained over the 10 and 20 year periods, and using the material substitution values in Section 7, the estimates in Table 10 result:

Table 10: Carbon gain through material substitution after 10 and 20 years

Period	Woodland type		
	Conifer	Broadleaved	All
Material subst. gain after 10 years (tCO2)	209,020	6,030	215,050
Material subst. gain after 20 years (tCO2)	418,040	12,060	430,100

13.4. Carbon gain through woodfuel

Assuming that the current levels of production and the current product mix is maintained over the 10 and 20 year periods, and using the woodfuel values in Section 9, the estimates in Table 11 result:

Table 11: Carbon gain from woodfuel after 10 and 20 years

Period	Woodland type		
	Conifer	Broadleaved	All
Woodfuel C gain after 10 years (tCO2)	93,520	22,080	115,600
Woodfuel C gain after 20 years (tCO2)	187,040	44,160	231,200

13.5. Total carbon gains after 10 and 20 years

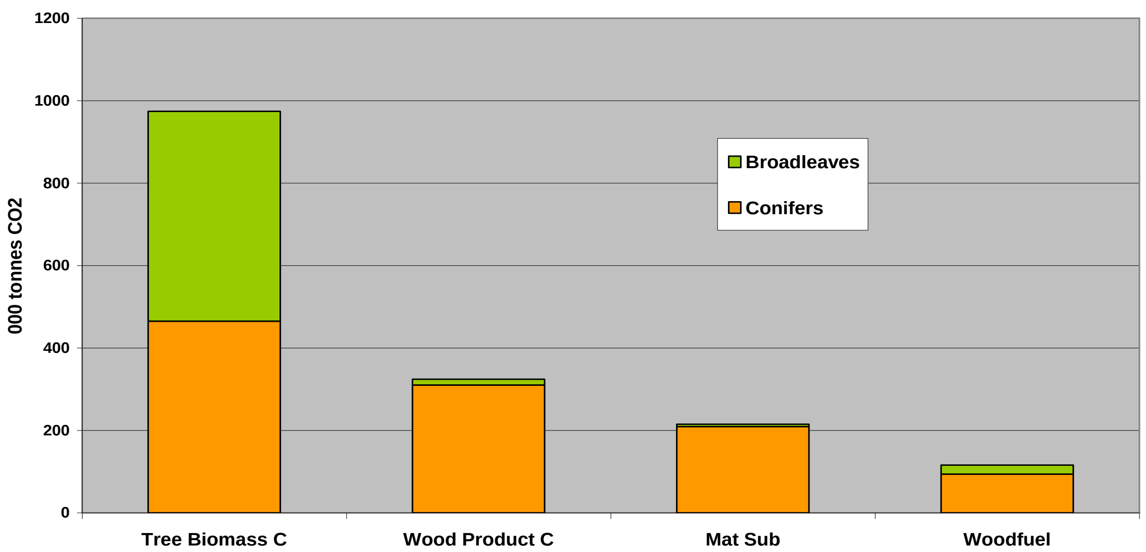
The estimates in Sections 13.1 to 13.4 generate the following total estimates of carbon gain over the 10 and 20 year periods:

Table 12: Total carbon gains over 10 and 20 years

Source of carbon gain	Period	Woodland type		
		Conifer	Broadleaf	All
Addition to tree biomass C store (tCO2)	10 years	465,380	509,260	974,640
	20 years	930,760	1,018,520	1,949,280
Addition to wood product C store (tCO2)	10 years	310,340	14,000	324,340
	20 years	612,320	28,000	640,320
Material subst. C gain (tCO2)	10 years	209,020	6,030	215,050
	20 years	418,040	12,060	430,100
Woodfuel C gain (tCO2)	10 years	93,520	22,080	115,600
	20 years	187,040	44,160	231,200
Total carbon gain (tCO2)	10 years	1,078,260	551,370	1,629,630
	20 years	2,148,160	1,102,740	3,250,900
Operational emissions (tCO2) (see Section 10)	10 years	13,560	550	14,110
	20 years	27,120	1,100	28,220
Net carbon gain (tCO2)	10 years	1,064,700	550,820	1,615,520
	20 years	2,121,040	1,101,640	3,222,680

The values in Table 12 for the 10 year period (excluding emissions) are shown in Chart 3 below:

Chart 3: Carbon Gains over 10 years in LDNP woodlands



The values in Table 12 are presented on a per hectare basis in Table 13 below

Table 13: Carbon gains per hectare

Source of carbon gain	Period	Carbon gain per hectare (tCO2)					
		Conifer		Broadleaf		All	
		tCO2	%	tCO2	%	tCO2	%
Addition to tree biomass C store	10 years	37.0	43	39.0	92.4	38.0	60.0
	20years	74.0	43	78.0	92.4	76.0	60.0
Addition to wood product C store	10 years	24.7	29	1.05	2.5	12.6	19.8
	20 years	48.7	29	2.1	2.5	25.0	19.8
Material substitution C gain	10 years	16.6	19	0.45	1.1	8.4	13.2
	20 years	33.2	19	0.9	1.1	16.8	13.2
Woodfuel C gain	10 years	7.4	9	1.7	4.0	4.5	7.0
	20 years	14.9	9	3.4	4.0	9.0	7.0
Total carbon gain (tCO2)	10 years	85.7	100	42.2	100	63.5	100
	20 years	170.8	100	84.4	100	126.8	100
Net carbon gain (tCO2)	10 years	84.6		42.2		63.0	
	20 years	168.6		84.4		125.7	

The net carbon gain over the next 10 years is therefore estimated at just over 1.6 million tonnes of CO2, and almost exactly twice that over the 20 year period. The net carbon gain from conifer woodland is almost twice that of broadleaved woodland on a per hectare basis. The largest source of carbon gain (43%) in conifers comes from the increase in carbon stored in tree biomass: with broadleaves almost all the carbon gain (92.4%) comes from this source. The caveats described at 13.1 above should however be noted.

14. Carbon gains from bringing neglected woodland into management

The view of local forest managers is that the great majority of conifer woodlands in the Lake District National Park are currently being managed, although some of the higher elevation plantations are under a non-thin regime. 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 LDNP: if the woodlands are understocked it would increase the carbon gain from bringing them into management. 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**

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 the LDNP, to assess the carbon and other impacts which would result from increased levels of management.

15. Carbon gains through woodland creation

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

A. Native broadleaved woodland – 40% YC 4 oak
40% YC 4 ash/birch/alder/rowan
20% shrubs and open ground

B. Conifer woodland – 30% YC 14 Sitka spruce
20% YC 16 Douglas fir
30% YC 10 Scots pine
10% native broadleaf (as above)
10% open ground

C. Mixed woodland – 50% of each of the above

Excel spreadsheets and charts for these 3 models, and the assumptions underlying them, are provided in Appendix 4. The results are summarised in Table 8 below.

Table 8: Carbon gains for LDNP woodland creation models

Element	Carbon gains after 100 years (tonnes CO2 per hectare)		
	Native	Mixed	Conifer
Tree biomass	336.0	445.6	555.2
Wood products	20.8	58.8	96.9
Material subst.	16.9	76.1	135.4
Woodfuel	70.1	87.3	104.5
Total C gain	443.8	667.8	892.0
Emissions	2.3	6.4	10.6
Total net C gain	441.5	661.4	881.4

The overall carbon gain for the conifer model is almost exactly twice that for the native woodland model over the 100 year period.

15. The wider context: carbon emissions in the Lake District National Park

A 2010 study by Small World Consulting estimated current greenhouse gas emissions in the Lake District National Park area as 2.3 million tonnes CO2 equivalent, of which 41% came from visitors travelling to and from the National Park. Following this study the LDNP Partnership developed "A carbon budget for the Lake District" which established an aim to reduce GHG emissions by 1% (23,000 tonnes) per annum.

The net carbon gain from the existing woodlands in the LDNP is estimated at 164,752 tonnes CO2 per annum, or 6.4 tonnes CO2 per hectare (see Table 7). Of this 66% comes from the conifer woodlands and 34% from the broadleaved woodlands. An improvement in the carbon performance of the existing woodlands of 1% per annum would therefore represent 7% of the National Park emissions reduction target. It is beyond the scope of this report to estimate what a realistic target for the existing woodlands might be but it appears to be achievable given in particular the probable underperformance of the older, understocked broadleaved woodlands.

The potential for new woodlands to contribute to the target is more straightforward. Using the mixed woodland creation model (Table 8) a planting programme of 350 hectares per annum would generate net emission reductions of 2,300 tonnes CO2 per annum, 10% of the target for the National Park.

16. Acknowledgements

The construction of this carbon account for the Lake District National Park woodlands has depended on considerable input of local knowledge and expertise from a number of woodland managers, sawmillers and other experts working in the area. In particular I would like to thank Neville Elstone of Cumbria Woodlands, Sam Hagon of the LDNP Authority and the University of Cumbria, Paul Clavey of United Utilities, Neville Geddes, David Woodhouse of Forest Enterprise, Stuart Palmer of the National Trust, Ian Jack of Lowther Estates, Alex Todd of Graythwaite

Estate, Harry Stevens of BSW, Peter Irving of Hutton Roof sawmill and Cameron Smith of Sheffield and Co.

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October 2012

Appendix 1

Carbon Stored in Tree Biomass in High Forest in Lake District National Park

Woodland Type		Planting Year Class									Totals
		1991-1999	1981-1990	1971-1980	1961-1970	1951-1960	1941-1950	1931-1940	1921-1930	Pre-1921	
Spruce	Area (ha)	1033	434	1157	1174	1558	717	437	18	175	6,701
	C store/ha (tCO2e)	51	280	396	559	500	556	597	626	653	
	Total C store (tCO2e)	52683	121520	458172	656266	779000	398652	260889	11268	114275	2,852,725
Larch	Area (ha)	30	192	95	401	916	388	518	257	391	3,189
	C store/ha (tCO2e)	117	341	384	455	374	407	429	444	463	
	Total C store (tCO2e)	3510	65472	36480	182455	342584	157916	222222	114108	181033	1,305,780
Other Cons	Area (ha)	144	163	225	226	353	427	399	208	543	2,688
	C store/ha (tCO2e)	18	148	271	365	339	384	422	449	486	
	Total C store (tCO2e)	25992	24124	60975	82490	119667	163968	168378	93392	263898	1,002,884
Ash/ Syc/ Birch	Area (ha)	73	162	174	194	1025	1134	912	841	402	4,917
	C store/ha (tCO2e)	58	241	376	460	493	517	527	537	556	
	Total C store (tCO2e)	4234	39042	65424	89240	505325	586278	480624	451617	223512	2,445,296
Oak	Area (ha)	62	46	0	36	172	541	441	391	3742	5,432
	C store/ha (tCO2e)	5	43		470	514	563	611	653	703	
	Total C store (tCO2e)	310	1978		16920	88512	304540	269555	255323	2630626	3,567,764
Other Bdls	Area (ha)	38	36	135	231	517	511	337	364	540	2,709
	C store/ha (tCO2e)	9	49	280	426	455	507	563	615	686	
	Total C store (tCO2e)	342	1764	37800	98406	235235	259077	189731	223860	370440	1,416,655
Totals	Area (ha)	1380	1033	1786	2262	4541	3718	3044	2079	5793	25,636
	Total C store (tCO2e)										12,591,104

Appendix 1 cont.

Notes:
1. **Spruce model is SS YC 14, unthinned for post 1980 stands, 50% thinned for 1960-1980, 100% thinned for pre-1960**
2. **Larch model is EL YC 10, unthinned for post 1980 stands, 50% thinned for 1960-1980, 100% thinned for pre-1960**
3. **Other conifers model is SP YC 8, unthinned for post 1980 stands, 50% thinned for 1960-1980, 100% thinned for pre-1960**
4. **Ash/sycamore/birch model YC 4, unthinned for post 1960, 20% thinned for pre-1960**
5. **Oak model is YC 4, unthinned for post 1960, 20% thinned for pre-1960**
6. **Other broadleaves model is beech YC 4, unthinned for post-1960, 20% thinned for pre-1960**
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. Emissions excluded**
9. **Values include carbon stored in stems, branches, foliage and roots.**
10. **Carbon stored in soils is not included**
11. **Stands in the 1991-1999 age class are taken to be 15 years old, those in the 1981-1990 category are taken to be 25 years old and so on.**

Appendix 2

Current Annual Carbon Sequestration in Tree Biomass in Woodlands in the Lake District National Park

Woodland Type		Planting Year Class									Totals
		1991-1999	1981-1990	1971-1980	1961-1970	1951-1960	1941-1950	1931-1940	1921-1930	Pre-1921	
Spruce	Area (ha)	1033	434	1157	1174	1558	717	437	18	175	6,701
	C seq/ha (tCO2e)	19.7	18.1	15.7	12.8	6.1	4.2	3.6	2.2	1.2	
	Total Seq (tCO2e)	20350	7855	18165	15027	9504	3011	1573	40	210	75,735
Larch	Area (ha)	30	192	95	401	916	388	518	257	391	3,189
	C seq/ha (tCO2e)	28.1	15.6	7.5	5.6	3.5	2.8	1.5	1.4	1.0	
	Total Seq (tCO2e)	843	2995	712	2246	3206	1086	777	360	391	12,616
Other Cons	Area (ha)	144	163	225	226	353	427	399	208	543	2,688
	C seq/ha (tCO2e)	6.6	25.6	10.6	7.6	4.7	4.0	2.7	2.5	1.7	
	Total Seq (tCO2e)	950	4173	2385	1718	1659	1708	1077	520	923	15,113
Ash/ Syc/ Birch	Area (ha)	73	162	174	194	1025	1134	912	841	402	4,917
	C seq/ha (tCO2e)	19.0	15.6	9.1	8.9	2.9	1.6	1.4	1.1	0.2	
	Total Seq (tCO2e)	1387	2527	1583	1727	2972	1814	1277	925	80	14,292
Oak	Area (ha)	62	46	0	36	172	541	441	391	3742	5,432
	C seq/ha (tCO2e)	1.8	19.0		8.0	5.4	5.3	4.6	4.5	4.1	
	Total Seq (tCO2e)	112	874		288	929	2867	2029	1759	15342	24,200
Other Bdls	Area (ha)	38	36	135	231	517	511	337	364	540	2,709
	C seq/ha (tCO2e)	1.5	14.6	19.3	10.4	5.6	5.6	5.6	5.3	4.6	
	Total Seq (tCO2e)	57	526	2605	2402	2895	2862	1887	1929	2484	17,647
Totals	Area (ha)	1380	1033	1786	2262	4541	3718	3044	2079	5793	25,636
	Total Seq (tCO2e)	23699	18950	25450	23408	21165	13348	8620	5533	19430	159,603

Appendix 2 cont.

Notes:
1. **Spruce model is SS YC 14, unthinned for post 1980 stands, 50% thinned for 1960-1980, 100% thinned for pre-1960**
2. **Larch model is EL YC 10, unthinned for post 1980 stands, 50% thinned for 1960-1980, 100% thinned for pre-1960**
3. **Other conifers model is SP YC 8, unthinned for post 1980 stands, 50% thinned for 1960-1980, 100% thinned for pre-1960**
4. **Ash/sycamore/birch model YC 4, unthinned for post 1960, 20% thinned for pre-1960**
5. **Oak model is YC 4, unthinned for post 1960, 20% thinned for pre-1960**
6. **Other broadleaves model is beech YC 4, unthinned for post-1960, 20% thinned for pre-1960**
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. Emissions excluded.**
9. **Values include carbon stored in stems, branches, foliage and roots.**
10. **Carbon stored in soils is not included**
11. **Stands in the 1991-1999 age class are taken to be 15 years old, those in the 1981-1990 category are taken to be 25 years old and so on.**

Appendix 3

1. Annual removals of carbon in harvested wood products: conifers

Species		Volume harvested (m3 OB per annum)				Total tCO2 removed
		7-14cm	14-18cm	Over 18cm	Total Vol	
Spruce	FC	6980	5228	21778	33946	
	Other	5066	3816	15898	24780	
	Total	12046	9044	37676	58726	35,528
Larch	FC	2003	1223	4994	8220	
	Other	1662	1015	4145	6822	
	Total	3665	2238	9139	15042	11,582
Other cons	FC	1562	1131	2992	5685	
	Other	2156	1561	4129	7846	
	Total	3718	2692	7121	13531	10,148
Totals	FC	10505	7582	29764	47851	
	Other	8884	6392	24172	39448	
	Total	19389	13974	53936	87299	57,258

Notes: 1. FC volumes are from the FC Production Forecast for LDNP woodlands
2. Other volumes are pro rata to FC volumes by area of woodland in the species group
3. Carbon densities used are: spruce – 0.605 tCO2/m3
larch – 0.77 tCO2/m3
other conifers – 0.75 tCO2/m3

2. Annual removal of carbon in harvested wood products: broadleaves

Species		Planting Year Class				Total tCO2 removed
		1941-1960	1921-1940	Pre-1921	Totals	
Ash/syc/birch	Area (ha)	2159	1753	402	4314	
	Vol<18cm (m3)	345	140	16	501	476
	Vol>18cm (m3)	259	70	16	345	328
Oak	Area (ha)	713	832	3742	5287	
	Vol<18cm (m3)	371	233	449	1053	1,085
	Vol>18cm (m3)	29	233	1646	1908	1,965
Other bdls	Area (ha)	1028	701	540	2269	
	Vol<18cm (m3)	575	308	86	969	891
	Vol>18cm (m3)	0	84	20	104	96
Totals	Area (ha)	3900	3286	4684	11870	
	Vol<18cm (m3)	1291	681	551	2523	2,452
	Vol>18cm (m3)	288	387	1682	2357	2,389
	Total Vol (m3)	1579	1068	2233	4880	4,841

Notes: 1. Woodland areas are from NIWT (1999)
2. All broadleaved species are assumed to be YC 4
3. No harvesting in stands planted after 1960
4. 20% of stands older than 1960 are thinned with volume removals as in FC Booklet 34
5. Carbon densities used are: ash/syc/birch – 0.95 tCO2/m3
oak – 1.03 tCO2/m3
other broadleaves – 0.92 tCO2/m3

Appendix 4: Woodland creation models Excel spreadsheets and graphs

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