Forest Research

The construction of lookup tables for estimating changes in carbon stocks in forestry projects

A background document for users of the Forestry Commission's Woodland Carbon Code

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July 2011

The Research Agency of the Forestry Commission

Summary

- This paper outlines how carbon lookup tables were constructed for use during the pilot phase of the Forestry Commission's "Woodland Carbon Code".
- The tables are designed to allow the estimation of future carbon sequestration in new woodland carbon projects in which no physical assessment is possible.
- Values of carbon stock were derived from existing computer models being routinely used and further developed by the Forestry Commission's Research Agency.
- The tables give 'default' estimates of carbon stock for 'in-forest' material (and quantity extracted) expressed as average annual values over sequential five-year periods from the time of woodland creation to 200 years.
- Lookup tables have initially been produced to cover a limited range of tree species and management scenarios and are selected by the end-user on the basis of:
    - tree species,
    - initial tree spacing at establishment,
    - estimated yield class, and
    - planned management thinning type.
- The values presented in the lookup tables for each species and management scenario are:
    - 5-year period to which the values apply,
    - average annual in-period rate of carbon sequestration in standing (live) material (t CO_2e/ha/yr),
    - average annual in-period rate of carbon sequestration in debris (dead material) (t CO_2e /ha/yr),
    - average annual total in-period rate of 'in forest' carbon sequestration (live + dead material) (t CO_2e /ha/yr),
    - total rate of carbon sequestration over the 5 year period (t CO_2e/ha/5 yrs),
    - cumulative total carbon sequestered from year zero to the end of the current period (t CO_2e/ha), and
    - average annual carbon removed from the forest as harvested and extracted material during the 5-year period (t CO_2e/ha/yr)
- Soil carbon is not accounted for in the lookup tables, which relate only to carbon contained in tree biomass (in-forest and extracted).

Acknowledgements

The authors wish to thank Robert Matthews, Ewan Mackie (Forest Research) and Vicky West (Forestry Commission GB) for helpful comments and suggestions relating to the various drafts of this document.

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Construction of Default Carbon Stock Tables

1. Introduction

The purpose of this document is to provide background information relating to the creation of default carbon stock tables as part of the Forestry Commission's Integrated Forest Carbon Review (Morison *et al*., 2011) and the Woodland Carbon Code (Forestry Commission, 2011).

The default carbon stock tables are derived from computer models and are designed for use where no inventory data are available for a forestry carbon project (*e.g.* while the project is in the planning stages).

This document makes no attempt to discuss the use and interpretation of the tables[1].

The tables were generated from a linked series of well established and robust models which have been developed by members of the Forest Measurement Modelling and Forecasting research group (previously known as the Forest Resources Evaluation Group) within the Forestry Commission's Forest Research Agency.

Using the modelling approach described in Chapter 6 of Morison *et al*. (2011), estimates of carbon stocks were produced for all major UK forest species at their 'standard' initial planting spacing and to represent growth under both 'standard'[2] and 'no-thin' thinning regimes.

For this initial study, estimates of carbon accumulation (or losses) have been produced for stands of forest trees grown for 200 years from establishment. Five yearly reporting periods have been used in order to minimise the effects of year to year variation in growing conditions, while still adequately representing stand growth in terms of its changing vigour throughout its life.

In-forest stock changes are tabulated as average annual values for each five year period from establishment (*i.e.* 0-5 years old, just over 5-10 years old, just over 10-15 years

1 Use of the tables is fully described in "Estimating woodland carbon sequestration from the Carbon Lookup Tables Version 1.3" (West & Matthews, 2011) currently published at: http://www.forestry.gov.uk/forestry/INFD-8JUE9T

2 The assumed 'standard' thinning regime is an intermediate type thinning undertaken at 100% marginal thinning intensity on a 5-year cycle.

old … just over 195-200 years old). In order to account for material removed during thinning operations (where undertaken), figures are also presented for trees scheduled for removal during each five year period.

2. Modelling the carbon dynamics in forest stands

The sequestration to and release of carbon from forest stands can be estimated using carbon accounting models, as described in Chapter 6 of Morison *et al*. (2011).

The carbon estimates in the lookup tables for the Forestry Commission's Woodland Carbon Code are based on the output from CSORT, the more sophisticated successor to the Forestry Commissions' Forest Research Agency's CARBINE model (Thompson and Matthews, 1989). CARBINE was designed to provide estimates of the amounts of carbon in standing tree biomass (above and below ground), forest litter, soils and harvested wood products as well as providing estimates of the potential reductions in emissions due to utilisation of harvested wood as a source of bioenergy and renewable material.

Forest carbon accounting models in use in Britain refer to the Forestry Commission's yield tables (Edwards and Christie, 1981) for basic growth and yield predictions. The FC yield tables present growth and yield estimates based the GB averages for each of the many combinations of tree species, initial planting spacing, growth rate and management regime modelled. It is important to recognise that the actual pattern of growth observed in an individual stand of trees may therefore occasionally deviate slightly from the GB averages presented in the yield tables. Some degree of care should therefore always be exercised when national models, such as those which underpin the carbon lookup tables, are applied at the local scale.

Although the lookup tables will usually provide reliable estimates of carbon stocks it is nevertheless recommended that, once a carbon project has been established, the estimates of carbon stocks originally derived from the lookup tables are followed-up with a direct assessment using the most appropriate field method documented in Jenkins *et al*. (2011).

The Forest Research CSORT model has been designed to work in conjunction with M1 (Arcangeli *et al.* in prep; Jenkins *et al.*, 2010), a new dynamic model of forest growth and yield which allows for the representation of a wider range of possible stand management regimes than is possible with CARBINE. Because of its increased functionality, CSORT has therefore been the model of choice for the production of the lookup tables supporting the Forestry Commission's Woodland Carbon Code.

A full description of the estimation of forest C and GHG balances using CSORT, including a comprehensive description of the model, is presented in Morison *et al*. (2011).

The objective has been to produce tables of default carbon values for all major tree species likely to be used in forest carbon projects established in line with the Forestry Commission's Woodland Carbon Code (Forestry Commission, 2010) and managed according to a selected number of 'standard' management regimes. It would not be practical to produce default values for every possible combination of species, growth rate, initial spacing and management regime. It will therefore be up to the user to make the necessary adjustment to the tabulated default values in these cases. It is anticipated that guidance will be provided in future publications to demonstrate applicable methodologies; for example for adjusting for wider- or narrower-than-tabulated initial spacings.

3. Estimating values for the lookup tables

3.1. CSORT outputs

A comprehensive description of the outputs of CSORT is presented in Morison *et al*. (2011).

The following primary outputs were used in the construction of the default lookup tables:

- stand age (years);
- total growing stock carbon (C, tonnes per hectare) contained in the above- and below-ground biomass of live trees;
- carbon (CO_2e, tonnes per hectare) emitted during mechanised forest operations such as thinning and harvesting;
- carbon (C, tonnes per hectare) contained in the tree biomass removed from the forest during thinning and harvesting operations;
- carbon (C, tonnes per hectare) contained in the tree biomass remaining in the forest as debris (including stumps and roots, other harvesting residues, standing dead trees and leaf litter).

All outputs were converted to CO_2 equivalents.

Values in the tables are presented as annual averages applicable to each five-year period between zero and 200 years. The choice of 5-yearly intervals within the tables is the result of several factors:

- many parts of the forest industry are familiar with the 5 year intervals traditionally used to predict yield and for short-term management planning
- a 5-year average is sufficient to smooth annual variations in growth rates caused by good and bad growing seasons
- a 5-year average is small enough to adequately reflect changes in growth rate throughout the life-cycle of a stand of trees.

All values in the tables assume that stands are, and remain, fully stocked. No allowance is made for the presence of any unproductive areas (*i.e.* no gross:net area conversion factor has been applied).

It is worth restating that soil carbon is not included in the lookup tables, which relate only to carbon contained in tree biomass.

An example of the change over time of the carbon stocks in a thinned stand is illustrated in Figure 3.1. The 'saw teeth' clearly visible in three of the curves are the result of carbon stock changes due to thinning operations, and will obviously not be present in the comparable curves for unthinned stands. The decreasing magnitude of the 'saw teeth' results from the fact that if a fixed thinning volume continues to be removed as growth of the stand slows (*i.e.* beyond the age of maximum mean annual volume increment), the stand will, in effect, be 'thinned to extinction' over time. This is caused because, beyond the age of maximum MAI, the standard thinning intensity increasingly exceeds the growth increment within the stand[3]. This would eventually lead to the complete removal of the standing material. To avoid this happening, the volume of timber removed at each thinning event is proportionately reduced beyond the age of maximum MAI.

[3] For description of the pattern of stand growth, and the construction of yield tables, please see Edwards, P.N. and Christie, J.M. (1981) *Yield models for forest management.* Forestry Commission Booklet 48. Forestry Commission: Edinburgh.

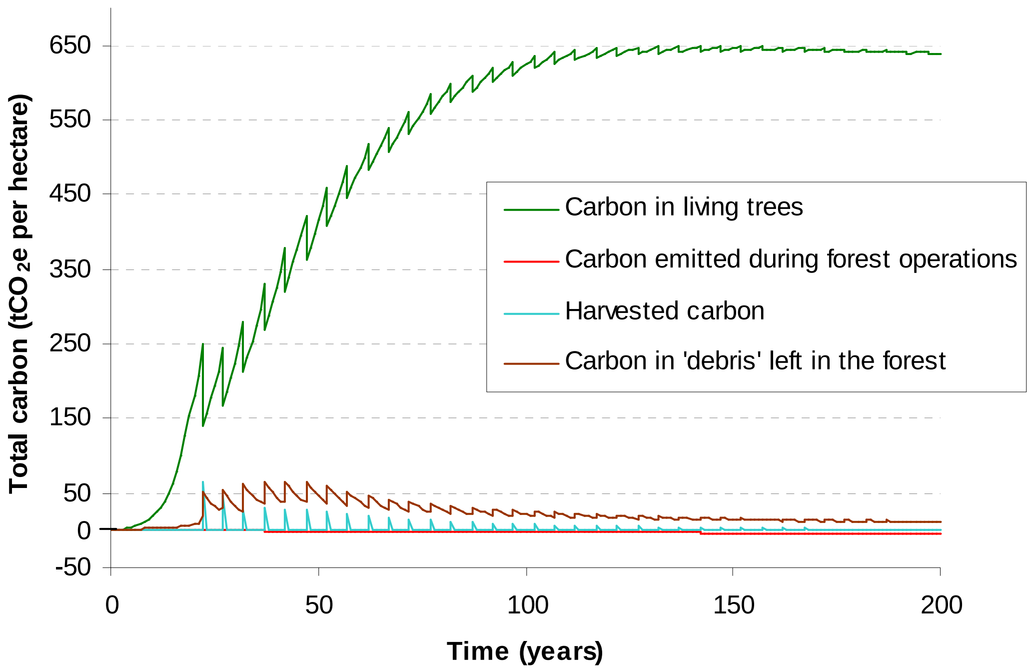

Figure 3.1 A graphical representation of the key CSORT outputs for a thinned stand. The graph presents the carbon in the various components, converted to tonnes of CO_2 equivalent per hectare. The volume of material removed during each thinning operation is reduced as the stand grows beyond the age of maximum MAI (approximately 50 years) in order to avoid 'thinning to extinction'.

4. The structure of the lookup tables

The lookup table produced is a Microsoft Excel spreadsheet which allows the user to access the average annual carbon values by five-year period (columns 5 to 13) by applying the input values (columns 1-4) relevant to the stand of trees for which those data are required . The structure of the lookup tables is summarised in Table 4.1.

Table 4.1 Description of Fields in the Woodland Carbon Lookup Tables (from West & Matthews, 2011).

Purpose	Column	Contents	Units
Input values – Choose the situation most suited	A	Species	Standard abbreviation
	B	Initial Spacing	metres
	C	Yield Class	Standard yield classes
	D	Management	Standard thinning or no thinning
Rate of carbon sequestration in each period.	E	Period	years
	F	Standing carbon	tCO_2e/ha/year
	G	Debris	tCO_2e/ha/year
	H	Total Carbon	tCO_2e/ha/year
	I	In-period cumulative total C	tCO_2e/ha/5-years
Cumulative CO_2e sequestered over time in the biomass	J	Cum. Biomass Sequestrn	tCO_2e/ha
Cumulative Emissions from Ongoing woodland management	K	Cum. Emis. Ongoing Mgmt.	tCO_2e/ha
Total Cumulative CO_2e sequestered over time	L	Cumulative Total Sequestrn	tCO_2e/ha
For information only: Carbon removed from forest during thinning	M	Removed from forest	tCO_2e/ha/year

5. Other considerations

5.1. Precision

5.1.1. Yield tables and management

The growth and yield model on which the lookup tables are based, is recognised as being accurate at the large (*e.g.* GB-wide) scale. Variations do however occur at smaller scales; clearly a yield class 12 Scots pine stand on a Scottish hillside is likely to exhibit somewhat different growth characteristics to a yield class 12 stand of Scots pine growing in Norfolk. It is assumed that such minor local differences will, however, tend to average out over a larger scale.

In creating the stock changes, a number of management assumptions have been made. These specify that stands in carbon projects will be managed according to ‘standard protocol’ rather than for management convenience or to satisfy market forces.

5.1.2. Debris

The estimation of material in forest debris is perhaps the area where one could expect significant variation. In reality many site-specific factors will influence the rate of decomposition of forest debris. Climatic conditions (temperature, rainfall, *etc*.) have a direct influence and microbial, fungal and animal presence and activity *etc*. (Woodall and Liknes, 2008). The decay rates used in the construction of the lookup tables are based on the assumption of reasonably good conditions for the growth of saprophytic organisms. The modelled debris pools may therefore decay faster than might always be observed in the field.

5.2. ‘Non-standard’ management regimes

In this study, results have been limited to a narrow range of management options; *i.e.* standard spacing and subject either to a standard thinning regime or left unthinned. Clearly many other regimes of establishment and management exist. No attempt is made to demonstrate these here, although the general methodology described above would remain the same. The initial tables are designed to cover the most common forest management scenarios. It may be that further development is needed to cover the other commonly practiced scenarios. For example, a method has had to be developed to adjust tabulated values for wider spacing, for which no bespoke yield tables exist (Jenkins 2010).

It should be noted that outputs for a no-thin stand and an identical stand which is designated to be thinned will give consistent outputs up until the time of first thin. After the first thin, a different average tree profile is assumed between the two management options, leading to differing biomass estimations.

6. References

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Woodall, C.W. and Liknes, G.C. (2008). Climatic regions as an indicator of Forest coarse and fine woody debris stocks in the United States. *Carbon Balance and Management* **3**:5. 8pp

Appendix 1: List of 'standard' tables

Table A1.1: Table showing the 'standard' management scenario, initial spacing and yield class combinations.

Tree Species	Management scenario	Initial spacing (m)	GYC range ($m^3ha^{-1}yr^{-1}$)
BE	'no thin'	1.2	4-10
BE	'thin'	1.2	4-10
BE	'no thin'	2.5	4-10
BE	'thin'	2.5	4-10
BE	'no thin'	3.0	4-10
BE	'thin'	3.0	4-10
CP	'no thin'	1.4	6-20
CP	'thin'	1.4	6-20
DF	'no thin'	1.7	8-24
DF	'thin'	1.7	8-24
EL	'no thin'	1.7	4-12
EL	'thin'	1.7	4-12
GF	'no thin'	1.8	12-30
GF	'thin'	1.8	12-30
HL	'no thin'	1.7	4-14
HL	'thin'	1.7	4-14
JL	'no thin'	1.7	4-14
JL	'thin'	1.7	4-14
LEC	'no thin'	1.5	12-24
LEC	'thin'	1.5	12-24
LP	'no thin'	1.5	4-14
LP	'thin'	1.5	4-14
NF	'no thin'	1.5	10-22
NF	'thin'	1.5	10-22
NS	'no thin'	1.5	6-22
NS	'thin'	1.5	6-22

Tree Species	Management scenario	Initial spacing (m)	GYC range ($m^3ha^{-1}yr^{-1}$)
OK	'no thin'	1.2	4-8
OK	'thin'	1.2	4-8
OK	'no thin'	2.5	4-8
OK	'thin'	2.5	4-8
OK	'no thin'	3.0	4-8
OK	'thin'	3.0	4-8
RC	'no thin'	1.5	12-24
RC	'thin'	1.5	12-24
SP	'no thin'	1.4	4-14
SP	'thin'	1.4	4-14
SS	'no thin'	1.7	6-24
SS	'thin'	1.7	6-24
SS	'no thin'	2.0	6-24
SS	'thin'	2.0	6-24
SAB	'no thin'	1.5	4-12
SAB	'thin'	1.5	4-12
SAB	'no thin'	2.5	4-12
SAB	'thin'	2.5	4-12
SAB	'no thin'	3.0	4-12
SAB	'thin'	3.0	4-12
WH	'no thin'	1.5	12-24
WH	'thin'	1.5	12-24