Additional forest data and information from Ireland to accompany the informal submission by Sweden on behalf of the European Community and its Member States on forest data

1. Afforestation patterns in pre-1990 (Article 3.4) forests, forest management systems and associated age class structure, and impact on emissions and removals

Ireland's forest cover at the beginning of the 20th century was 1.4% of the area of the country[a]. From the 1920s afforestation programmes have increased forest cover to the present level of over 10%[b]. Most the pre 1990 forest therefore dates from the 20th century, during which there have been significant fluctuations in the afforestation rate, particularly since the 1940s (Figure 1).

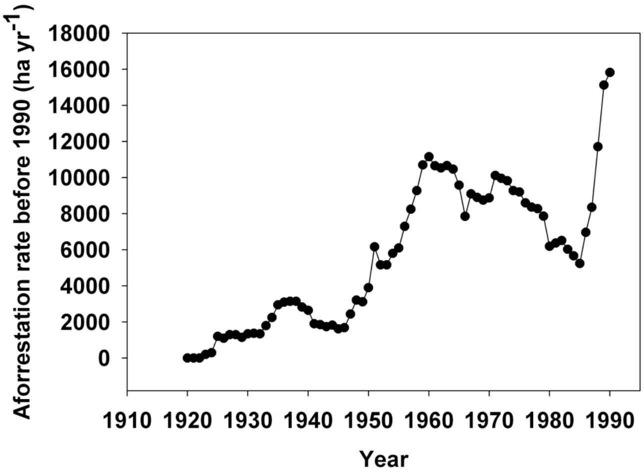

Figure 1: Afforestation rate in Ireland, 1920 to 1990 (source Forest Service).

Historical inventory records and sub-compartment management forecast plans show that there has been a shift in the age class distribution from a left skewed, young age class distribution in 1959 to a near-normal distribution curve by 1998 (Figure 2). However, there was a reversal towards the younger age class distribution by 2006, resulting from fell and replant as pre-1990 forests developed to the prescribed felling age. This trend is expected to continue up to 2012, and it is projected to be followed by a re-distribution towards older age classes up to 2020.

Shifts in age class frequency are consistent with historic afforestation rates and mean rotation ages of 41 and 39 for Sitka spruce and lodgepole pine (Table 1), the main species in pre-1990 forests (where they comprise 94 % of timber fellings). Pre 1990 forests are predominantly state-owned (89 %).

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[a] OCarroll, N. 2004. *Forestry in Ireland – A Concise History*. COFORD, Dublin.

[b] NFI. 2007. *The National Forest Inventory of Ireland*. Forest Service, Dublin.

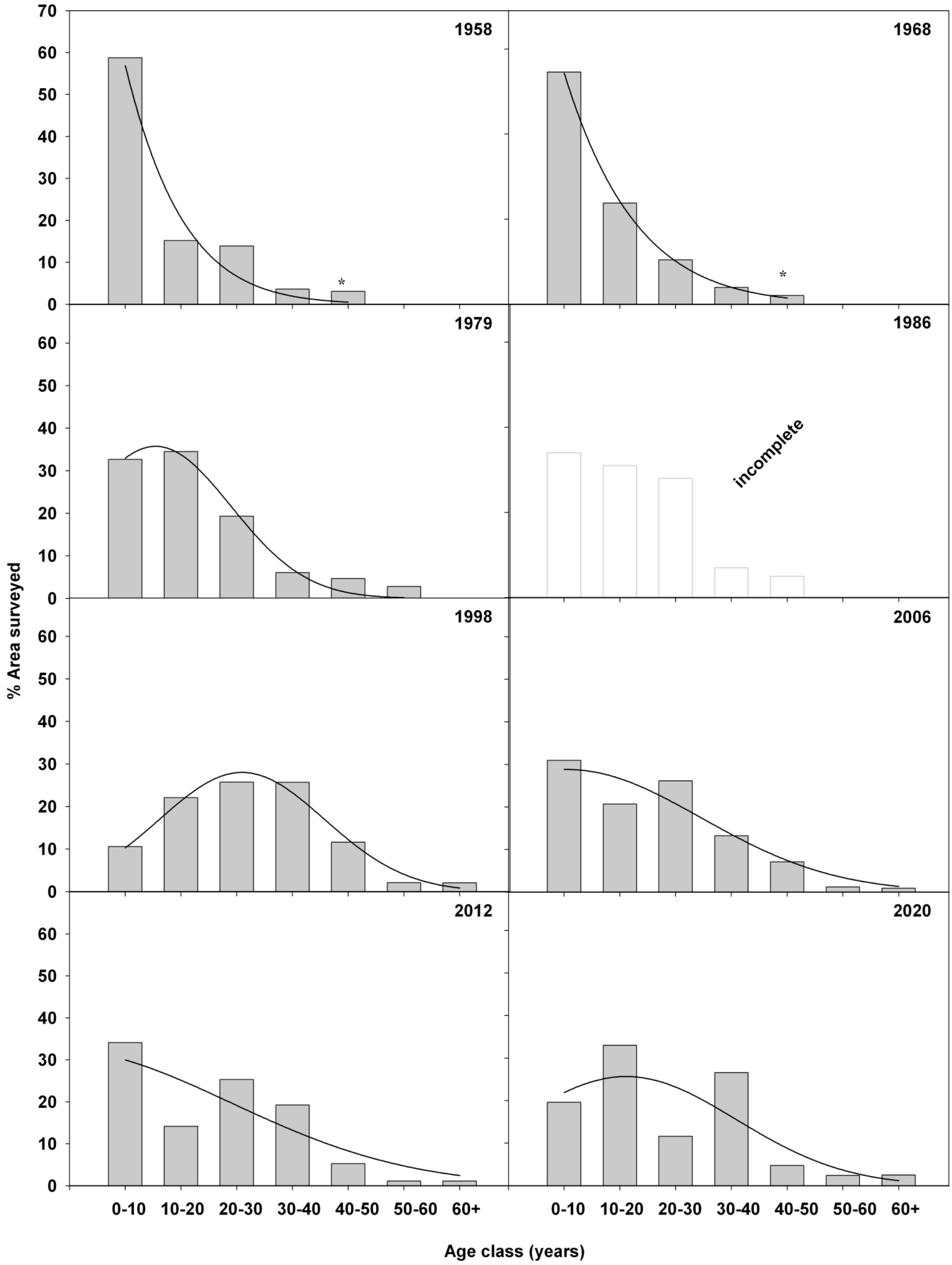

Figure 2: Age class frequency distributions of pre-1990 forests over successive decades from 1958, and projected to 2012 and 2020 based on summary statistics (grey histograms) and fitted distribution curves (solid lines) using a Gaussian function.
* The 1959 and 1968 data do not segregate age classes beyond 50 years of age.

The shifts in the age class distribution are considered to influence current and projected forest emission/removals in pre-1990 forests in two ways:

a) A *decrease in biomass increment*. There is evidence of a decline in gross biomass increment between 1998 and 2020. This is associated with a change in the mean age and age class frequency[c] and a consequent decline in annual sequestration rate in younger crops, following replanting after clearfell.

b) *A decrease in the deadwood C pool*, due to the residual C decomposition of harvest residue following the first rotation. This C loss is carried over to second rotation crops for a period of ca. 30 years[c].

Table 1: Mean rotation ages of forest species from forecasted sub compartment and management unit data for the period 2008 to 2020. (Abbreviations: n is the number of sampled compartments, MMAI is maximum mean annual volume increment, n/a not applicable because a rotation age of MMAI is applied to those species).

Species	Forecast rotation age	Age at commercial rotation	Age at MMAI
Lodgepole pine (n = 53)			
Mean	39	40	57
Sitka spruce (n = 156)			
Mean	41	42	52
Norway spruce (n = 17)			
Mean	40	36	51
Others (n = 18)			
Mean	48	n/a	59

2. New estimates of historic and projected net emission trends in forest management and Article 3.3 forests

The evolution of reporting tools for carbon stock change in Irish forests - CARBWARE

The Irish forest carbon reporting system (CARBWARE v4.5), described by Gallagher et al. (2004) was initially implemented to meet reporting requirements to the UNFCCC on national forestland remaining forestland (F-F) and land converted to forestland (F-L). To facilitate the 20-year transition between F-L and F-F, CARBWARE v4.5 was specifically designed to generate a time series estimate going back to 1970 using species distribution activity data for young (7 to 25-year-old) and mature stands (>25 years, see Gallagher et al. 2004). The early version of CARBWARE was, however, a static model (i.e. had only two age classes), representing C dynamics for ten forest type cohorts (see Gallagher et al. 2004). In addition, the old model only considered C stock changes in the living biomass and litter pools, and assumed deadwood C stock changes are in steady state. However, the original model is still used, in combination with a newer version of CARBWARE, as a hybrid model (see Appendix A) because it enables the extent of C stock change to be estimated back to 1970. This forms the basis for historic data estimates for both UNFCCC categories and KP Article 3.4 forests (Figure 3).

CARBWARE v5 was used to estimate historic and projected Article 3.3 emission/reductions, based on forest inventory data, yield models and national research information (see Black and Farrell 2006, Black et al. 2009, Gallagher et al

[c] Black et al (in prep) Historic and projected carbon dioxide emission/removals for forest management under Article 3.4 of the Kyoto protocol (see extracts in Appendix A).

2004). The outputs from the new model (see CARBWARE v5 in Appendix A) are used to generate historical and projected data for activities relating to Articles 3.3 and projected data for Article 3.4 of the KP from 2008 onwards.

There may be a slight modelling bias in the historic and projected data for forest management (i.e. pre-1990 forests) due to inconsistencies in the time series brought about by treating younger and older age class cohorts separately in the hybrid model (see Appendix A). This was addressed by calibration with CARBWARE v5 and adjustment of the historic data to produce a consistent time series (Figure 3). This back-extrapolation adjustment is in accordance with prescribed procedures for national adjustments and compliance under Articles 5 and 7 of the Kyoto Protocol. There were no historic activity data available for use in the CARBWARE v 5 model.

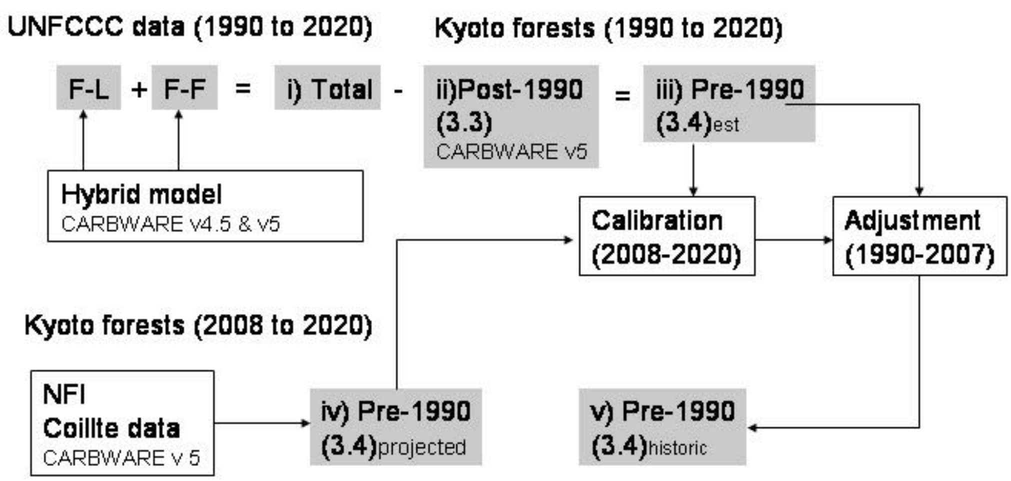

Figure 3: The overall modelling approach of the methodology used to generate the historic and projected time series for Article 3.4 forests. The initial estimates for Article 3.4 forests (box iii. Pre-1990 $(3.4)_{est}$) were calculated based on the difference between the sum of all forestland in the UNFCCC data (grey box i. Total) minus the Article 3.3 net emissions (ii. Post-1990 (3.3)) for the entire time series 1990 to 2020. To reduce any potential over or under estimation bias in the data due to the use of different models in the projections, the historic Article 3.4 data were calibrated and adjusted using back-extrapolation, based on the relationship between the projected Article 3.4 data (grey box iv. Pre-1990 $(3.4)_{projected}$) and the UNFCCC-derived data (grey box iii. Pre-1990 $(3.4)_{est}$). The current approach adopted to calculate Article 3.4 projected data (grey box iv. Pre-1990 $(3.4)_{projected}$) was based on CARBWARE v5 using activity data derived from the intersected NFI and Coillte (State forestry company) sub-compartment data (as used to derive the age class distribution for 2006 onwards).

3. Projected change in forest cover

Estimates of forest cover in 2015 and 2020 were based on current rates of afforestation (ca 7,000 per year at present, rising to 10,000 ha per year by 2012 based on the government policy - p 11 *Renewed Programme for Government,* 2009 (and see http://www.taoiseach.gov.ie/eng/Publications/Publications_2009/Renewed_Programme_for_Government,_October_2009.pdf).

In the previous EU data submission we submitted an average deforestation area of 1000 ha per year for the historic and projected time series. It was also assumed that the emission from deforestation was 415 t CO_2 per ha, based on the mean C stock at rotation age for Sitka spruce crops. This was based on expert judgement. However, based on the availability of new data sources, we have decided to revise this estimate. These sources come from newly developed databases (2006-2008) compiled by the Forest Service Limited Felling Licence application system, which legally requires landowners to supply information on areas and volumes deforested. The new data suggests that the expert judgement was an overestimate and that the deforestation areas are similar to the data submitted to the UNFCCC. In addition, it was evident from analysis of the new data that the emission from deforestation is nearly 3-fold lower than originally estimated. This is because most of the forest land deforested comprised on low productivity and younger age classes as previously assumed. For the newly submitted data is now taken from the UNFCCC submission in the CRF table 5 E and the NIR submitted to the convention. This methodology is outlined in the NIR submission.

Appendix A
Further methodological background

Derivation of harvest and activity data

The pre-1990 Coillte estate was used to estimate harvest in pre-1990 forest since this accounted for 89 % of the Article 3.4 pre-1990 forest in 2006 (NFI 2007). The 2006 National Forest Inventory sample plot co-ordinates were used as a random systematic sample to select Coillte sub-compartments representing 35,533 ha or ca. 10% of the pre-1990 forest. The Coillte sub-compartment and management unit forecast attribute data were obtained by GIS intersection with the point co-ordinates from the NFI permanent sample plots. This enabled a representative age-class distribution to be determined for the 2006 forest and project the age class distributions forward to 2020 using the harvest forecast in the management unit plans.

Historic harvest data was obtained from UNECE/FAO. All harvested roundwood was assumed to come from the pre-1990 forests until the end of 2008 (Table 2). All harvest was assumed to be derived from the pre-1990 forest up to 2008.

The harvest forecasts for 2009 to 2020 were derived from the Coillte sub-compartment/NFI sample plot intersects as described above. The harvest forecast from 2015 to 2020, as supplied, was not smoothed (Coillte smoothes the harvest forecast by bringing forward and postponing harvest by up to 2 years in order to avoid large annual fluctuations in roundwood supply). The forecasted Coillte harvest, after 2015, was smoothed using linear interpolation (Table 2).

Table 2: Historic and forecasted harvest roundwood volumes from the pre-1990 forest.

Harvest volume in pre-1990 forest (M m^3)				
UNECE/FAO harvest		Forecast harvest		
			Smoothed	Un-smoothed
1990	1.787	2009	2.209	-
1991	1.837	2010	1.883	-
1992	2.156	2011	2.061	-
1993	2.003	2012	2.314	-
1994	2.220	2013	2.390	-
1995	2.424	2014	2.109	-
1996	2.520	2015	2.402	2.863
1997	2.398	2016	2.558	2.099
1998	2.493	2017	2.704	2.687
1999	2.842	2018	2.870	2.922
2000	2.940	2019	3.026	2.534
2001	2.700	2020	3.182	3.647
2002	2.911			
2003	2.951			
2004	2.818			
2005	2.913			
2006	2.938			
2007	2.981			
2008	2.213			

Replanting of clearfelled areas was assumed to take place 2 years after harvest. It was also assumed that all clearfelled forest areas would be replanted, unless management plans indicated a planned deforestation event.

Harvest production forecasting

A forecast of roundwood production is produced for each stand (sub-compartment) in Coillte's pre-1990 forest estate[d]. The inputs to the forecasting process are:

1. Inventory data at the sub-compartment level comprising species composition, planting year, yield class (productivity index), area, species canopy percentage and stocking.

2. Silvicultural management prescriptions for each stand, referred to as the Thinning and Rotation Classification (TRC) based on yield models (Forestry Commission (FC), Forest Service and Coillte modified models), together with volume assortment tables (Irish Sitka spruce and FC assortment tables).

3. Each subcompartment is assigned a Thinning and Rotation Classification (TRC). The thinning classification indicates the type and number of thinnings a stand will receive throughout its rotation. The rotation classification indicates the age at which the stand will be clearfelled. The inventory data and the TRC are used to select an appropriate yield model. The selected model is then used to produce volume and size estimates for each thinning and clearfell.

4. The sub-compartment based roundwood production estimates are aggregated to forest, regional and national level. The forecast is then smoothed to provide an even pattern of supply to the roundwood processing sector. The production shown for each year is designed to overcome sharp fluctuations in yield that can take place from year to year which relate to previous planting patterns.

5. Roundwood harvest estimates are gross overbark standing volumes; harvesting losses have not been deducted. The forecasted volumes from the pre-1990 estate was called up to the national level and converted to CO_2 emissions using a basic density of 0.4 kg m^{-3} and a carbon content of 50 % (Black et al., 2004; Black and Farrell, 2006)

6. Forecasted harvest volumes are broken down into top diameter categories: $7 \leq 14$, $14 \leq 20$ and 20+ cm, with a minimum log length of 3 m.

7. The projected harvest data represent the best estimate of likely future production. The gross figures are based on the summation of the impacts of the current management plans for each stand.

[d] The Coillte roundwood production forecast (updated 2006) is available at http://www.coillte.ie/fileadmin/user_upload/pdfs/Forecast_web_final_2006.pdf.

DESCRIPTION OF MODELS USED

The hybrid CARBWARE model

The historic net emissions for forestland remaining forestland and land converted to forest (i.e. the Convention reporting format, see i. in Figure 3) were calculated using a hybrid model based on CARBWARE v4.5 (described above) and the newer dynamic model (CARBWARE v5).

The net emissions for the F-F and F-L categories (Figure 3) were estimated using the original methodology as described in previous Convention submissions (CARBWARE v4.5; see Gallagher et al., 2004, NIR, 2004, 2005, 2006) with the following modifications:

1. All areas replanted since 1990 were excluded from the model. These C stock changes were estimated using CARBWARE v5.
2. Soil stock changes were assumed to be at a steady state after 20 years, following a land use transition into forest.
3. Soil and deadwood stocks were also assumed to be at steady state in forestland remaining forestland. This is consistent with the 20-year transition and default values recommended in the IPCC 2006 GPG.

CARBWARE v5

Estimates of changes in biomass over time were based on the new version of CARBWARE (v5), using forest growth models and research information from current and previous COFORD-funded projects (CARBiFOR, CARBWARE, FORESTSOILC, see Black and Farrell 2006, Black 2008). A common approach used to report regional annual C stock changes or interpolate between inventory measurements involves mass-balance ($NEP_{\Delta C}$) estimates (IPCC 1996). This is normally based on models/measurements which describe the changes in biomass (ΔC_b), litter (ΔC_{litter}), dead wood ($\Delta C_{dead\ wood}$) and soil (ΔC_{soil}) C pools:

$$NEP_{\Delta C} = \Delta C_b + \Delta C_{litter} + \Delta C_{dead\ wood} + \Delta C_{soil} \qquad (2)$$

The dynamic CARBWARE v5 growth model describes changes in ΔC_b based on tree-level allometric functions (for example DBH and top height) and stand attributes (stocking) for representative species, according to Forestry Commission yield models (Edwards & Christy 1981, Black & Farrell 2006). For this exercise, stand attributes such as age, mean DBH, top height, stocking and timber harvested, for six species cohorts (spruce, fir, larch, pine, slow-growing and fast-growing broadleaves), were used as inputs for the calculation of cumulative stand biomass using species-specific allometric relationships (Black et al. 2004, Black et al. 2007, Tobin et al. 2006, Black & Farrell 2006).

A modified expo-linear growth function (Monteith 2000) was used to more accurately simulate growth during the early years of the rotation and interpolate growth over time, since neither the dynamic or static models consider growth of young forest (<10 years old).

Stand biomass (*St*) was expressed as:

$$St = Mt\left[\frac{1 - e^{-k_s(k_t - t)}}{1 - e^{-k_s k_t t}}\right] \qquad (3)$$

where;

$$Mt = \frac{Cm}{Rm} \ln\left[1 + \frac{Co}{Cm} e^{Rmt}\right] \quad (4)$$

Mt is Monteith's function, where *Cm* is maximum growth rate, *C*o is initial absolute growth rate, *R*m is the initial relative growth rate and *t* is time (years). Parameters *Cm, Rm, Co,* k_s and k_t were fitted using the least squares optimisation method to estimated stand biomass values.

The current annual increment (ΔC_b) for any given year was then calculated as:

$$\Delta C_b = St_{n+1} - St_n \quad (5)$$

The same approach was used to calculate aboveground and belowground biomass changes.

Stands due for thinning in the pre-1990 forest, as specified by the Coillte management plans were, were subjected to thinning at a marginal thinning intensity (Christy and Edwards, 1981) since volumes removed due to proposed thinnings were not indicated. The volumes removed at clearfell age (i.e. the age specified in the Coillte management plan) were based on the CARBWARE biomass stock at the time of harvest, using a biomass expansion factor of 1.4 and a basic density of 0.4 kg $m^{-3.}$ The model outputs for volume removed at harvest were compared with the historic harvest and Coillte forecast (2009 to 2015) roundwood volumes for model optimisation.

For the Article 3.3 projection we assume that 50 % of the post 1990 forest was subjected to thinning as described for the specific cohorts (at marginal thinning intensity, see Edwards and Christy 1981). CARBWARE v5 also simulates carbon stock change in un-thinned stands modified from Forestry Commission stand-level models (Edwards and Christy 1981).

The biomass model also simulates the changes in other C pools, such as litter, and deadwood for different species and management scenarios, based on research information (Black et al. 2004, 2007, 2009a In press; Tobin et al. 2006, 2007, Saiz et al. 2007).

Annual litter gains and losses ($\Delta C_{litter} = C_{1gain} - C_{1loss}$) were calculated based on foliar biomass functions, litter fall models (Tobin et al. 2006), estimates of harvest residue and decomposition factors;

$$C_{\lg ain} = (Fb \times Ft) + Br \quad (6)$$

where *Fb* is foliage biomass (t C ha^{-1}), *Ft i*s leaf or needle turnover rate (*Ft* = 0.2 (i.e. 5 years) for evergreen conifers (Tobin et al. 2006) and *Ft* = 1 for deciduous species). *Br* is brash (harvest residue in the form of branches and needles) added to the litter pool. Brash (*Br* < 7cm diameter) was calculated as:

$$Br = AG_{harvest} - Tm_{harvest} \quad (7)$$

where *AG* (Total biomass – belowground biomass, BG) is aboveground biomass and *Tm* is roundwood cut at harvest (DBH ≥7cm, t C ha^{-1}).

Emissions from the accumulated litter pool ((ΔC_{loss}) for any given year (*n*) were calculated as a function of litter turnover rates (*Lt*) based on experimental data (*Lt* = 0.14; Saiz et al. 2007).

$$C_{lloss_{(n+n)}} = \sum \left[\left(C_{\lg ian_{(n)}} \times Lt\right)\left(C_{\lg ain_{(n)}} \times (1 - Lt)\right) + C_{\lg ain_{(n+n)}} \times Lt \right] \quad (8)$$

The dead coarse wood C pool ($C_{dead\ wood)}$ includes C gains ($C_{d.gain}$) and decomposition losses ($C_{d.loss}$).

$$C_{d.gain} = st + hr + tr + mort \quad (9)$$

where *mort* is mortality (as specified in both the static yield tables and dynamic yield model), *st* and *hr* represent stumps and roots of harvested trees (total biomass harvest - $AG_{harvest}$) and *tr* is the harvest residue of remaining wood on site after harvest (assumed to be 5 % of the biomass from the $Tm_{harvest}$ pool).

The clearfell harvest residue losses were also applied to sub-compartments clearfelled since 2000 to account for the historic deadwood and litter decomposition losses in the model.

Characterisation of age class distributions

Historic age class and forest area summary statistics from previous state and Coillte forest inventory records were obtained for the years 1959, 1968, 1979, 1986 and 1998. The frequency distributions for historic data were generated from age class histograms with a 10 year bin class using a Gaussian 3 parameter non-linear model (see Figure 2, SigmaPlot v7.0, SPS Inc, USA). The same procedure was repeated for the 2006 sample and projected data for comparison purposes.

Gini coefficients and Lorenz curves were used, as they are a measure of inequality of distribution (Sadras & Bongiovanni, 2003). The Lorenz curve, in our case, was used as a measure of inequality of the age classes in the pre 1990 forest.

Use of the Gini coefficient (G) is also preferred because of its relative robustness to slight changes in the right tail of plant size distribution data (Hay et al. 1990):

$$G = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} \left| x_i - x_j \right|}{2\, xn(\bar{n} - 1)} \quad (10)$$

where x_i is the age of the *i*th sub-compartment in the samples population, x bar is the mean population age, and n in the population density. Gini coefficients (G) are a numerical representation of the Lorenz curve and vary between 0 and 1, with a value of 0 depicting an evenly distributed age class distribution.

References and bibliography

OCarroll, N. 2004. *Forestry in Ireland – A Concise History*. COFORD, Dublin.

O'Flanagan, L. 1973. *Inventory of Private Woodlands.* The Stationery Office, Dublin.

O'Muirgheasa, N. 1964. *Forest Research Review 1957-1964*. Department of Lands Forestry Division. Stationery Office, Dublin.

Hay, M.J.M., Thomas, V.J. and Brock J.L. 1990. Frequency distribution of shoot weight of plants in populations of Trifolium repens grazed pastures. *J. Agr. Sci.*: 553-558.

Black, K., Tobin, B., Saiz, G., Byrne, K. and Osborne, B. 2004. Improved estimates of biomass expansion factors for Sitka spruce. *Irish Forestry* 61: 50 –65.

Black, K., Bolger, T., Davis, P., Nieuwenhuis, M., Reidy, B., Saiz, G., Tobin, B. and Osborne, B. 2007. Inventory and Eddy Covariance Based Estimates of Annual Carbon Sequestration in a Sitka spruce (Picea sitchensis (Bong.) Carr.) Forest Ecosystem.

Forest Ecosystem. *Journal of European Forest Research* 126: 167-178. (doi 10.0007/sl0342-005-0092-4).

Black, K. and Farrell E.P. eds. 2006. *Carbon Sequestration in Irish Forest Ecosystems*. COFORD, Dublin.

Black K.G. 2007. Scaling up from the stand to regional level: an analysis based on the major forest species in Ireland. Proceedings of the 2nd International Workshop on Uncertainty in Greenhouse Gas Inventories (IIASA), Laxenburg, Austria (*in press*).

Black, K. 2008. Ireland's forest carbon reporting system. In: *Proceedings of COFORD conference on: Forestry, Carbon and Climate Change - local and international perspectives*. Eds Hendrick, E and Black. K. COFORD, Dublin.

Hendrick, E., and Black K. 2008. Climate change and Irish forestry. COFORD Connects Note, Environment No 9. COFORD Dublin.

Black, K., O'Brien, P., Redmond, J., Barrett, F. and Twomey, M. 2009. The extent of peatland afforestation in Ireland. *Irish Forestry* 65: 61-71.

Black, K., Byrne, K., Mencuccini, M., Tobin, B., Nieuwenhuis, M., Reidy, B., Bolger, T., Saiz, G., Green. C., Farrell, T. and Osborne, B. 2009b. Carbon stock and stock changes across a Sitka spruce chronosequence on surface water gley soils. *Forestry*, In press.

Dewar, R.C. and Cannell, M.G.R. 1992. Carbon sequestration in trees, products and soils of forest plantations: an analysis using UK examples. *Tree Physiology* 11: 49-71.

Edwards, P.N. and Christie, J.M. 1981. *Yield models for forest management*. Forestry Commission Booklet no. 48. HMSO, London.

Hargreaves K.L., Milne, R. and Cannell, M.G.R. 2003 Carbon balance of afforested peatland in Scotland. *Forestry* 76(3): 299-317

Gallagher, G., Hendrick, E. and Byrne K. 2004. Preliminary estimates of biomass stock changes in managed forests in the Republic of Ireland over the period 1900-2000. *Irish Forestry*: 61: 16-35.

Saiz, G., Black, K., Reidy, B., Lopez, S. and Farrell, E.P. 2007. Assessment of soil CO2 efflux and its components using a process-based model in a young temperate forest site. *Geoderma*, doi: (*in press*) 10.1016/j.geoderma. 2006.12.005

Redmond J. 2007. Proceedings of Ireland's National Forest Inventory Conference. Forest Service, Dublin (ISBN 0-7557-7563-5).

Tobin, B., Black, K., Osborne, B., Reidy, B., Bolger, T. and Nieuwenhuis, M. 2006. Assessment of allometric algorithms for estimating leaf biomass, leaf area index and litter fall in different aged Sitka spruce forests. *Forestry* 79(4): 453-465, doi 10.1093/forestry/cpl030.