Establishment of Ireland's projected reference level for Forest Management for the period 2013-2020 under Article 3.4 of the Kyoto Protocol

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Abstract

There is increasing evidence that the extent to which managed forests can sequester carbon dioxide (CO_2) from the atmosphere is influenced by changes in forest area, age class structure and management practice. Signatory parties to the Kyoto Protocol can elect to account for CO_2 removals associated with Forest Management (confined to pre-1990 forest) under Article 3.4. A premise in formulating accounting rules under the Protocol was that forest sinks should be directly linked to direct human-induced activities. However, carbon (C) stock change in forests is also due to indirect human-induced activities. Indirect factors include increases in atmospheric CO_2 concentration, nitrogen deposition, and age class legacy effects resulting from historic forest management and afforestation activities. Current accounting frameworks attempt to factor out indirect human induced activities by setting a limit (cap) on accountable CO_2 removals or by setting a historic time series baseline (reference level), from which accountable annual removals/emissions can be derived. However, it is argued that these proxies do not factor out historic Forest Management effects (age-class legacies), which disincentivise parties from electing article 3.4 accounting. It is proposed that the use of a projected reference level, which considers age-class structure, can factor out dynamic age-class effects. Effects of indirect human induced activities are considered to be approximately the same in the projected reference level period and in the estimated period (i.e. the commitment period), and therefore they can be assumed to be factored out. However, election of Forest Management under article 3.4 using these newly proposed accounting rules requires development of national systems for forecasting future forest emissions and removals, as well as a methodology to characterise the effects of age class structure on the C balance of managed forests. In this paper, we outline methodologies used to derive a national C stock change reference level for Forest Management activity under Article 3.4 of the Kyoto Protocol for the period 1990 to 2020. We characterise the effects of age class and management legacy on C stock change over historic and projected time series. Different accounting frameworks are compared in relation to compliance with the Marrakesh Accords and ability to provide incentives to enhance sink capacity through Forest Management. We suggest that a projected reference level is best suited to accounting, factoring out legacy effects, and for providing an incentive framework to encourage additional mitigation activities under the Forest Management activity of Article 3.4 of the Kyoto Protocol. It is suggested that the projected reference level approach also factors out indirect human induced effects provided, that the same methodological approaches are used for both the projected reference level and the reported time series.

Keywords: *Forest carbon sinks, carbon accounting, age-class legacy.*

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Introduction

Ecosystem greenhouse gas (GHG) balance in temperate and boreal forests is largely influenced by forest management activities (Magnani et al. 2007). It is suggested that afforestation and changes in forest management have contributed to net C uptake (sink) in Northern Hemisphere forests (Ciais et al. 2008). In addition, relationships between forest productivity or net ecosystem uptake and stand age or management are well understood (Mund et al. 2002, Desai et al. 2005).

C sinks and emissions (sources) resulting from Forest Management (the activities specified in the Marrakech Accords and confined to forests in existence before 1990) were electable (on a voluntary basis) under Article 3.4 of the Kyoto Protocol for the period 2008-2012. Ireland and a number of other countries did not elect to report the activity, primarily due to lack of data and uncertainty regarding the implications of such a choice.

Accounting rules for Forest Management post 2012 are under negotiation in the United Nations Framework Convention on Climate Change (UNFCCC) process. A key issue is the establishment of a reference level of emissions/removals[1]. Other important issues include how to deal with large emissions resulting from fires, insect outbreaks and other disturbances, and the treatment of emissions from harvested wood products (Donlan et al., 2012).

The current (2008-2012) accounting rules were set out in the Marrakesh Accords in 2001 and the Kyoto protocol entered into in 2005. Adopted accounting rules were supposed to exclude indirect human-induced removals (sinks). These include the effects of elevated CO_2 levels, indirect nitrogen deposition and the dynamic effects of age structure resulting from activities and practices before the reference year (onset of the commitment period). Subsequent work by the International Panel on Climate Change (IPCC: Schimel and Manning 2003) concluded, however: "The scientific community cannot currently provide a practicable methodology that would factor out direct human-induced effects from indirect human-induced and natural effects for any broad range of land-use, land-use change and forestry (LULUCF) activities and circumstances." From an accounting perspective though, the rules governing Forest Management under Article 3.4 of the Kyoto Protocol for the first commitment period (2008-2012) cap[2] the amount of credits (for most Parties) on the basis of removing the effect of indirect human activities. This accounting rule was regarded as a proxy to direct human-induced change in forest C stocks.

The concept of projected reference levels (also known as a forward-looking baseline) was introduced to the negotiation process as a proposal to put in place an accounting system that did not reward BAU (business-as-usual activities- as can be the case in gross-net accounting[3]) and would be able to remove age-class legacy and other effects which could result in Parties incurring debits even though Forest Management would be a net sink in the period 2013-2020. The projected reference level also attempts to address other indirect effects, elevated CO_2 concentrations

[1] i.e. of GHGs to or from the atmosphere.
[2] A cap refers to an agreed limit of claimed C credits from forest management activities.
[3] See definition in next section.

(above pre-industrial levels), indirect nitrogen deposition, and the dynamic effects of age structure resulting from activities prior to 1st January 1990.

Implicit in the development of a projected reference level and in keeping up with UNFCCC GHG inventory and reporting processes, forest areas and emission factors should be complete, accurate, consistent, transparent and comparable across both historical (1990 to 2008) and projected time series (e.g. up to 2020). Furthermore, accounting for emissions/removals in future commitment periods should attempt to remove accountable age-class and related effects due to historic forest management practices or afforestation programmes prior to 1990 (legacy effects). Of course the selection of any specific historic reference level for Forest Management accounting will inevitably result in winners and losers (Böttcher et al. 2008), due to historic fluctuations in afforestation, felling and replanting rates (age class legacy) or changes in silvicultural policy such as rotation age or transition to continuous cover forestry (management legacy).

Calculating C stock change

The issuance of removal units (RMUs) for Forest Management under Article 3.4 is based on C stock change over time. A number of possible accounting methods are available, which express changes simply in the commitment period, or relative to a reference year or period. These are outlined below.

<u>Gross-net accounting</u>

This is the current accounting approach for Forest Management. No historic reference is applied; hence the gross stock change over the commitment period is used to calculate the potential level of credits or debits that will be issued for the activity during the commitment period. In this case the credit or debit over the first commitment period (C_{tc1}) is derived as (and see also Figure 1 as a guide):

$$C_{tc1} = \sum(C_{t1}...C_{tn}) \tag{1}$$

where Ct_n is the forest C stock change for each year of the first commitment period.

Using the examples in Figure 1, application of the gross-net accounting rule would result in zero removal units (RMUs – credits) for the commitment period for scenario 1 (S_1, Figure 1). In the case of scenario 2 (S_2), trends in the managed forest C balance would result in an accountable debit, despite the fact that forests are a sink over the time series (t_0 to t_n). In contrast, scenario 3 (S_3) would result in credits (i.e. a gross removal or sink), even though the forest C balance changes from a sink to a source over the time series.

A cap on Forest Management was included for the first commitment period in order to reduce the scale of Forest Management relative to emission reductions. However, because the cap was a politically negotiated value (for a number of Parties) it was disproportionately large in some cases. For example, the allowable claimed credits, per unit area, for Japan would be far greater than those for Canada (see Böttcher et al. 2008). Another disadvantage of the gross-net method is that it does not account for natural or indirect human induced influences and legacy effects brought about due to activities, such as afforestation, often carried out several decades before the advent of the UNFCCC process.

Net-net accounting

This is the accounting approach used for cropland and grazing land management, and revegetation under Article 3.4:

$$C_{tc1} = \sum(C_{t1} \ldots C_{tn}) - (C_{to} \times N) \tag{2}$$

Where C_{t0} is the forest C stock in the reference year (usually 1990) and N is the length of the commitment period in years.

Schlamadinger et al. (2007) suggested that this approach include long-term trends in C emissions or removals and should allow the factoring out of indirect human induced and natural effects[4]. Therefore, C emissions and removals over the commitment period are assumed to be a function of many factors, including age class structure. Figure 1 illustrates hypothetical scenarios represented by different age class shifts (over time t_0 to t_1), starting at the same C stock change value in 1990. Scenario 1 (S_1) represents a constant, (most likely normally-distributed) age-class structure over time. For the period to t_o t_n, S_2 and S_3 represent left-shifting (old to young) and right-shifting (young to old) age class structures, respectively. To illustrate the projected reference level concept, additional sub-scenarios are applied to S_1 only, based on a business as usual (BAU) projected baseline (see arrow from S_1 to S_{1a}), for the second commitment period (t_{c2}). Two different hypothetical C stock change scenarios for tc2 are applied to represent a harvest level above (S_{1c}) or below (S_{1b}) the BAU scenario (S_{1a}).

Based on the examples shown in Figure 1, S_1 would result in zero accountable RMUs, S_2 in net credits (RMUs) and S_3 in accountable emissions. However, net–net accounting would result in some countries having a net debit even if the change over the commitment period resulted in C uptake (see S_3 in Figure 1). These trends may be related to a change from a negatively-skewed age-class distribution (old) to a positively skewed distribution (young), with a net debit ensuing in the commitment period where the forest C stock had increased more in the reference year than in the commitment period. On the other hand, credits would result for countries with a right-shifted age structure in which C gains are higher due an increase in age-related productivity (e.g. see t_0 to t_1 in S_2, Figure 1).

[4] Natural effects may include insect infestations or disease outbreaks etc.

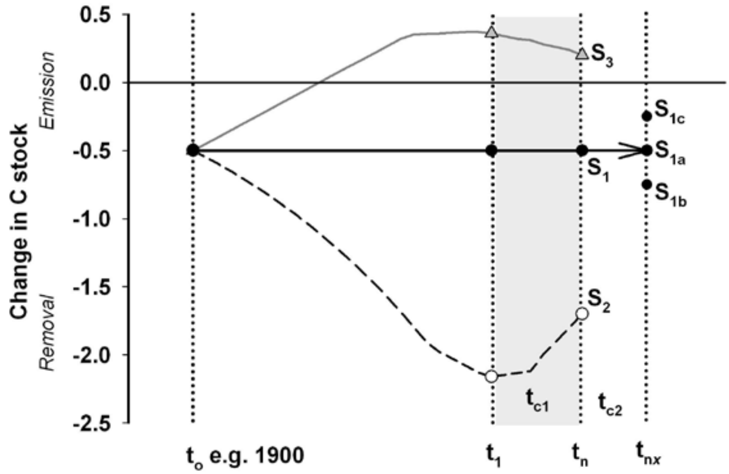

Figure 1: *Hypothetical forest management C stock changes for different scenarios (S_1, S_2 and S_3) over time: t_0 is reference level (for example 1990), t_1 is the start of the first commitment period (2008-2012), t_n is the end of the first commitment period, t_{nx} is the end of the second commitment period. Adapted from Böttcher et al. 2008. Refer to the text above for explanation of the different scenarios.*

Projected reference level or forward looking baseline?

An approach under negotiation in the UNFCCC LULUCF process (see latest version of draft text at http://unfccc.int/resource/docs/2011/awg16/eng/crp01.pdf [Accessed July 2012]) proposes to use a projected Forest Management reference level, based on net stock change in the period 2013-2020 using a BAU scenario. The approach is similar in some respects to net-net accounting but the reference (or bar) is a projected baseline (Figure 1, S_{1a}), which is compared to an *observed* C stock change over the same time period (Figure 1, S_{1b} or S_{1c}):

For example $S_{1b} \rightarrow C_{tc2} = \text{Obs. } C_{tn..nx} - \text{Proj.}Ctn_{.nx}$ (3)

where Obs. $C_{tn.nx}$ is the observed C stock change over the second commitment period (see S_{1b} in Figure 1);

$$\text{Obs. } C_{tn..nx} = \sum(S_1 C_{tn}, ..., S_{1b} C_{tn\,x}) \qquad (4)$$

And where Proj.$C_{tn..nx}$ is the C stock change projected forward over the same period (S_{1a} in Figure 1):

$$\text{Proj.}C_{tn..nx} = \sum(S_1 C_{tn}, ..., S_{1a} C_{tn\,x}) \qquad (5)$$

where C_{tc2} is the reference C stock change for scenario S_{1b} (see Figure 1).

This approach has the advantage of removing legacy effects, since they are included in the baseline and in the commitment period. Hence any deviation from the baseline is deemed to be directly attributable to a policy change, for example by increased or decreased levels of harvest compared with BAU. Using Figure 1 as an example, additional harvest over and above the BAU level would result in debits (see S_{1c}) and harvest below BAU would result in credits (S_{1b}). This approach provides a good basis for incentivising climate change mitigation activities in pre-1990 forests, but only where it can be transparently demonstrated that harvest differs from a predetermined BAU plan, and where forests are regenerated after harvest. Parties are required to justify that age class or management legacies influence current and projected C stock changes (see Appendix II of Decision 2/CMP.6 (FCCC/KP/CMP/2010/12/Add.1)).

The primary objectives of this study were to develop a method to estimate a consistent historical and projected time series, which is representative of Ireland's Forest Management activities under Article 3.4. We characterised changes in the age class distribution and management legacy of pre-1990 forests to investigate how these effects may have influenced historic and future (i.e. projected) national forest sinks. Currently proposed accounting methods are evaluated based on criteria for compliance with the Marrakesh Accords, but without dis-incentivising countries from election of these activities due to legacy effects. For example, it may be decided not to elect article 3.4 activities due to the introduction of management policies implemented a long time ago. Finally, we investigate the implications of electing Forest Management under the different accounting framework proposals.

Materials and methods

Compilation of historic age-class and forecast data

The pre-1990 Coillte estate was selected as a sample for the forest management areas since this accounted for 89% of the Article 3.4 forest in 2006 (NFI 2007). Afforestation records were obtained from the Forest Service (see Figure 2). Historic age class and forest area summary statistics from previous state and Coillte forest inventory records were obtained for 1959, 1968, 1979, 1986 and 1998 (See Table 1). The 2006 NFI sample plot co-ordinates were used as a random systematic sample points to select Coillte sub-compartments representing 35,533 ha or ca. 10% of the pre-1990 forest estate. Each sampled plot was scaled-up to the national level using the representative spatial sampling up-scaling factor of 400 ha[5]. The Coillte sub-compartment and management unit attribute data were obtained by GIS intersection with the point co-ordinates from the NFI permanent sample plots. This enabled a determination of a representative age-class distribution for the 2006 forest. The age-class distributions were projected forward to 2020 using the harvest forecast from the management unit plans.

Information on species composition, age, basal area, felling data and yield class,

[5] This is derived from the NFI sampling grid of 2 × 2 km, representing 400 ha.

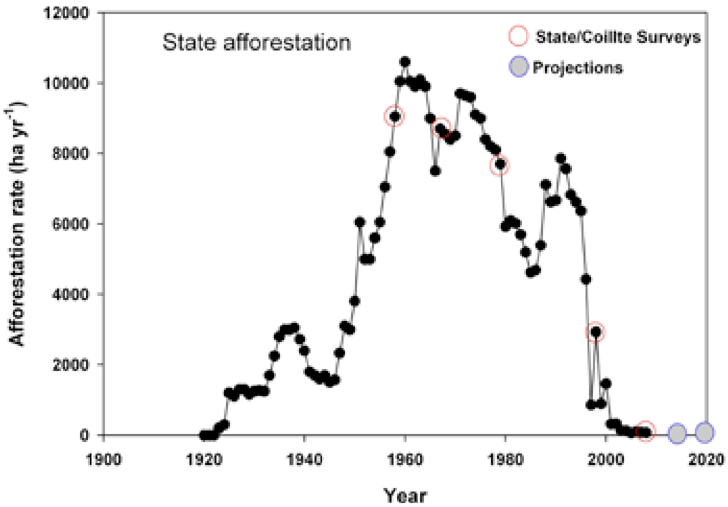

Figure 2: *Afforestation rates of state/Coillte forests since 1920 (Source: Forest Service) and survey years where age-class distribution analysis was performed based on historic and projected data sources.*

obtained from the Coillte sub-compartment and management records, was also used to estimate projected emissions/removals for Article 3.4 forest. The projected timber forecasts for the period 2010 to 2020 were obtained from the Coillte timber supply forecast (Anon. 2008). The harvest forecast from 2015 to 2020 (Coillte smoothes the harvest forecast to deliver a comparable year-on-year harvest and roundwood supply) was smoothed using linear interpolation.

Replanting of clearfelled areas was assumed to take place two years after harvest. We assumed all clearfelled forest areas were replanted (to comply with national forest legislation), unless management plans indicated a planned permanent deforestation event.

Characterisation of age class distributions

No raw data for the historic datasets were available. Therefore, the frequency distributions for historic data were generated from age-class histograms with a 10-year bin class using a Gaussian, three 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.

We used Gini coefficients and Lorenz curves because this is a measure of inequality of distribution of age classes (Sadras and Bongiovanni 2004). The Lorenz curve was developed in economic science as a wealth index, where a cumulative proportion of the population is plotted against a cumulative proportion of wealth. It is commonly standardised so that each axis ranges between 0 and 1 and represents the degree of inequality in the distribution of wealth or income in society. In this case, the Lorenz curve was used as a measure of inequality of the age classes in pre-1990 forest.

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

$$G = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} |x_i - x_j|}{2\,x n(\bar{n} - 1)} \tag{6}$$

where x_i is the age of the i^{th} sub-compartment in the sampled population, x_j is the mean population age, and n is the population density. Gini coefficients are a numerical representation of the Lorenz curve and range from 0 to 1, with a value of 0 depicting an evenly-distributed age-class frequency.

Adjustments for age class legacy

Following the estimation of historical trends, two approaches were adopted to make adjustments of age class legacy:

a) Historical time series adjustment.

This was achieved by applying the mean growth increment before harvest (GrossΔB) from the projected second commitment period to the baseline data, where the age class distributions were different. This was then weighted, based on the G coefficient and mean age class ratio, as shown in equation 7:

$$\text{Gross}\Delta\text{r}_{(\text{ref})} = A \times \text{meanGI}_{(\text{proj})} \times \left[\left(\frac{\text{Gcoeff}_{(\text{proj})}}{\text{Gcoeff}_{(\text{ref})}} \right) \div \left(\frac{\text{meanAge}_{(\text{ref})}}{\text{meanAge}_{(\text{prog})}} \right) \right] \tag{7}$$

where GrossΔB is the adjusted reference year gross biomass increment before harvest (t C yr^{-1}), A is the total forest area (ha) in the reference year, meanGI is the mean biomass increment before harvest for the projected years (i.e. 2.4 t C ha^{-1} yr^{-1}), Gcoeff is the G coefficient for the reference and projected years and, meanAge is the mean stand age in the reference and projected years.

b) A forward-looking baseline.

Using the approach of Böttcher et al. (2008), the Coillte harvest forecast was used to estimate the BAU baseline scenario (see Introduction, Figure 1).

Estimation of historic and projected emission/reduction trends

<u>The evolution of CARBWARE</u>

The Irish C 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 (7-25 year-old) and mature stands (>25 years; see Gallagher et al. 2004). The early version of CARBWARE was, however, a static model (it had two age classes only) representing C dynamics for two forest-type cohorts (conifers, based on Sitka spruce (*Picea sitchensis* (Bong.) Carr.) and broadleaves, based on beech (*Fagus sylvatica* L.) - 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 were in steady state. The original model is still used, in combination with a newer version of CARBWARE, to form a hybrid model, because it is able to extend C stock change estimates back to 1970. This forms the basis for historic data estimates for both UNFCCC and Kyoto Protocol Article 3.4 forests (Figure 3).

To facilitate Article 3.3 reporting requirements, CARBWARE has evolved from a Tier 2 to a Tier 3 (most specific and country-based reporting tier[6]) system, using forest inventory data, yield models and national research information (see Black and Farrell 2006, Black et al. 2009a, Gallagher et al. 2004). The outputs from the model are used to generate historical and projected data for activities relating to Articles 3.3 and projected data for Article 3.4 of the Kyoto Protocol from 2008 onwards.

<u>The hybrid CARBWARE model</u>

The historic emissions/removals 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 initial estimates for Article 3.4 forests (Figure 3; box *iii. Pre-1990 (3.4)*$_{estimated}$) were calculated based on the difference between the sum of all forestland in the UNFCCC data (dark green box *i. Total*) minus the Article 3.3 emission/removal (ii. Post-1990 (3.3)) for the entire time series 1990-2020. To reduce the potential for 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 (dark green box *iv. Pre-1990 (3.4)*$_{projected}$) and the UNFCCC derived data (dark green box *iii. Pre-1990 (3.4)*$_{estimated}$). The approach adopted to calculate Article 3.4 projected data (dark green box *iv. Pre-1990 (3.4)*$_{projected}$) was based on CARBWARE v5, using activity data derived from the intersected NFI and Coillte sub-compartment data (as used to derive the age class distribution for 2006 onwards).

The emissions/removals for *F-F* and *F-L* categories (Figure 3) were simulated using the original methodology as described in previous national submissions to the UNFCCC – "Convention submissions" (CARBWARE v4.5; see Gallagher et al. 2004, McGettigan et al. 2006) with the following modifications:

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

[6] Tiers refer to methodological rankings used as set out by the IPCC good practice guidance. Tier 1 refers to default methods, higher tiers use country-specific and increasingly more complex modelling approaches.

default values recommended in the IPCC 2006 Good Practice Guidance.

4. Mean accretion rate, which reallocates areas representing young forest into the old forest cohorts after 25 years, was replaced by actual areas. This was carried out to ensure that the there was no accretion of the Forest Inventory and Planning System (FIPS) data from 2014 onwards (i.e. 1989 was the last afforested and replanted area cohort moved to the old forest cohort). This meant that the pre-1990 forest C stock in old forests (>25 years) decreased from 2014, due to felling and no addition of new stocks due to replanting and reforestation. Similarly, C stocks of the new forest cohort (7-25 years old) were zero from 2006 onwards.

CARBWARE v5

Estimates of changes in biomass over time were based on the new CARBWARE v5, using forest growth models and research information from current and past COFORD-funded projects (Black and Farrell 2006, Black 2008, Wellock et al. 2011). A common approach that is used to report regional annual C stock changes or interpolate between inventory measurements involves mass-balance ($NEP_{\Delta C}$) estimates. This is normally based on models/measurements which describe the changes in biomass (ΔC_b), litter (ΔC_{1itter}), dead wood ($\Delta C_{dead\ wood}$) and soil (ΔC_{soil}) C pools:

$$NEP_{\Delta C} = \Delta C_b + \Delta C_{1itter} + \Delta C_{dead\ wood} + \Delta C_{soil} \qquad (8)$$

Stand biomass

The dynamic CARBWARE v5 growth model describes changes in ΔC_b based on tree-level allometric functions (for example diameter at breast height (DBH) and top height) and stand attributes (stocking) for representative species, according to Forestry Commission yield models (Edwards and Christy 1981, Black and 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 and Farrell 2006).

A modified expo-linear growth function (Monteith 2000) was used to more accurately simulate growth (DBH and height) 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:

$$St = Mt \left[\frac{1 - e^{-k_s (k_t - t)}}{1 - e^{-k_s k_t t}} \right] \qquad (9)$$

where:

$$Mt = \frac{Cm}{Rm} \ln \left[1 + \frac{Co}{Cm} e^{Rmt} \right] \qquad (10)$$

Mt is Monteith's function, Cm is maximum growth rate, Co is initial absolute growth rate and Rm 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:

$$\Delta C_b = St_{n+1} - St_n \tag{11}$$

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

CARBWARE v5 simulates the C stock changes in un-thinned stands modified from Forestry Commission stand-level models (Edwards and Christy 1981). Stand-level volumes removed due to proposed thinnings were not indicated in the Coillte management plan forecasts. In the Coillte forecast, thinning volumes were aggregated to national level. For the bottom-up stand level projection of thinned stands, we assumed that thinning occurred at marginal thinning intensity using thinning volumes based on static yield tables (see Edwards and Christy 1981). Stands were clearfelled when indicated in the forecast management unit and sub-compartment level plans. A timber (minimum top diameter of >7 cm) harvest extraction efficiency of 96% was assumed for all harvest activities. The CARBWARE v5 model outputs for volume removed at harvest were compared with the forecasted (2001 to 2015) timber volumes (Gallagher and O'Carroll 2001) and the Coillte forecast data (2008 to 2020) for model optimisation.

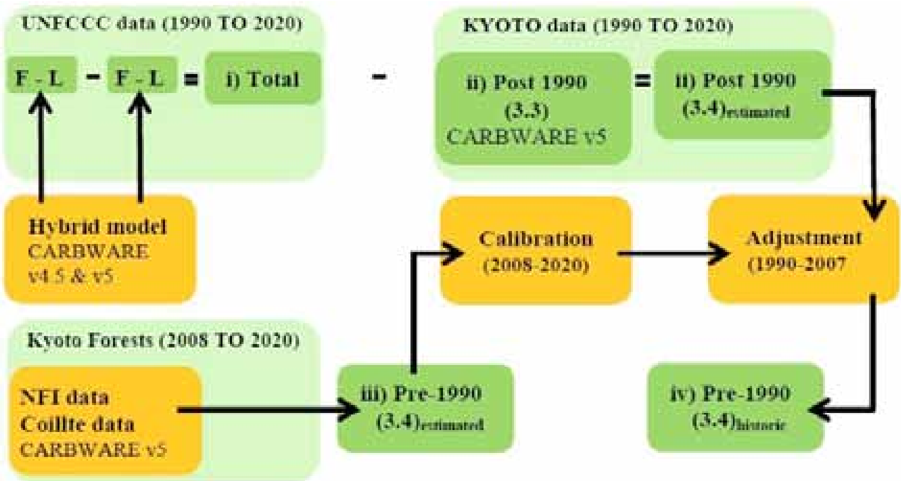

Figure 3: *The overall modelling approach for Article 3.4 forests showing the methodology used to generate the historic and projected time series. Refer to text for a detailed explanation of the approach.*

Other C pools

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, 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:

$$C_{lgain} = (FB \times Ft) + Br \tag{12}$$

where FB is foliage biomass (t C ha^{-1}), Ft is 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, needles and tree tops) added to the litter floor.

Brash (Br < 7 cm diameter) was calculated as:

$$Br = AG_{harvest} - Tm_{harvest} \tag{13}$$

where AG is total biomass – belowground biomass and Tm is timber cut at harvest (for trees whose DBH >7 cm, t C ha^{-1}).

Emissions from the accumulated litter pool (ΔC_{lloss}) 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) :

$$C_{lloss_{(n+n)}} = \sum \left[\left(C_{lgian_{(n)}} \times Lt \right), \left(C_{lgain_{(n)}} \times (1 - Lt) \right) + C_{lgain_{(n+n)}} \times Lt \right] \tag{14}$$

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

$$C_{d.gain} = st + hr + tr + mort \tag{15}$$

where mort is mortality (as specified in both the static yield tables and dynamic yield models), 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 4% 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. The CARBWARE v5 model assumes that all timber C is lost at harvest and does not account for C residence time in harvested wood products (HWP). This is in line with the current KP accounting rules. The treatment of HWP in the construction of the forest management reference level is discussed by Donlan et al. (2012).

Results and Discussion

Calibration of the hybrid model

Generally there was good agreement between the hybrid model and previously submitted UNFCCC data, particularly for the periods 2001 to 2007. There was a somewhat higher emission pre 2012 in the new projections, reflecting the growth patterns of younger forest, where the growth increment may be lower than the mean increment of 7 m^3 ha^{-1} yr^{-1} assumed by Gallagher et al. (2004).

There may be a slight modelling bias in the projections due to inconsistencies in the time series, brought about by treating younger and modelled forest separately in the hybrid model. 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 v5 model.

Age-class legacy effects

It is important to point out that Ireland's forest cover at the beginning of the 20th century had declined to 1.5% of the land area (OCarroll 2004). Afforestation programmes since that time have increased the forest area to just over 10% (NFI 2007). There was a rapid expansion in the state forest area after 1945 (Figure 2). This resulted in the afforestation of ca. 150,000 ha from 1948 to 1968. The mean age of the State/Coillte forests (afforested before 1990) increased from 13 years in 1959 to 28 years in 1998, followed by a slight decline to 22 years by 2006 (Table 1).

Table 1: *Summary of the areas sampled and source data for the age-class distribution analysis.*

Year	Area sampled (ha)	Mean age[a] (years)	Source	Comment
1959	55,226	13	O'Muirgheasa 1964	Afforested areas since 1948 added to data to include 1-10 year-old crops
1968	186,107	15	O'Flanagan 1973	Afforestation areas since 1959 included (as above)
1979	280,800	18	Anon. 1980	
1986	Data missing			
1998	315,967	28	Coillte records	Afforested areas since 1990 removed from data
2006	35,553	24	NFI/Coillte	
2012	35,553	22	NFI/Coillte	Projection based on forecast and management plans
2020	35,553	25	NFI/Coillte	As above

[a] Mean forest age was based on reconstructed age-class distributions using a Gaussian function (see Figure 4).

Figure 4 shows the age-distribution histograms over the time series. Based on these data, it is evident that there was a "right-shift" in the age-class distribution from a positively-skewed (young) age-class distribution in 1959 to a near normal distribution in 1998. However, there was a reversal (left-shift) towards the younger age classes by 2006. This trend continues up to 2012, followed by a right-shift towards older age classes in the projected 2020 time series. These age-class distribution shifts are consistent with historic afforestation rates and a mean clearfell age of ca. 42 years (i.e. commercial rotation of 20% less than the age at maximum mean annual volume increment of Sitka spruce, yield class 16 m^3 ha^{-1} yr^1, see Table 2) in place from the 1990s.

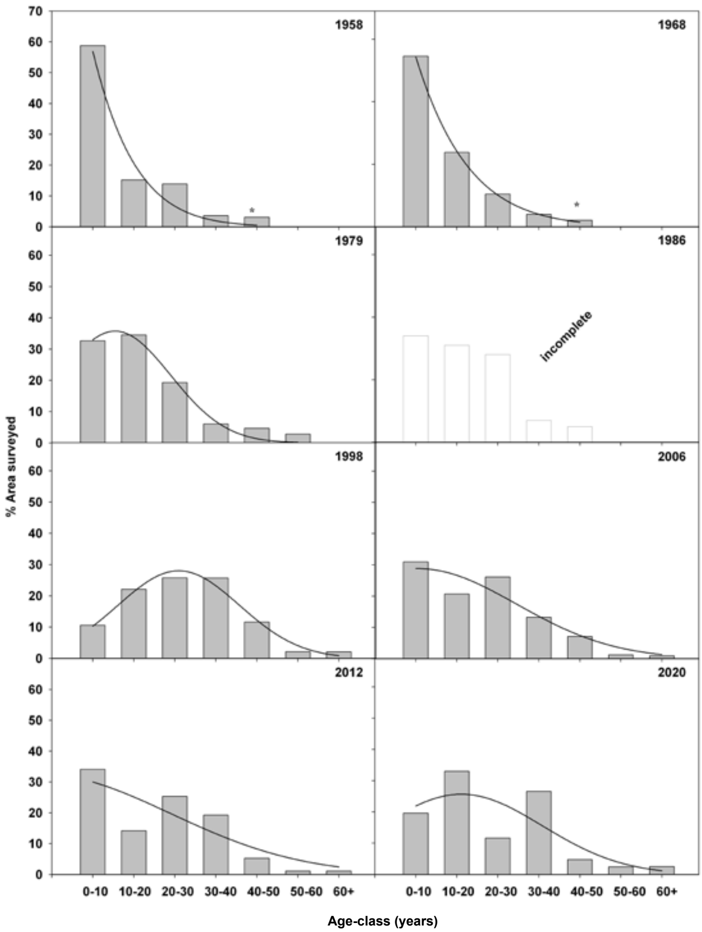

Figure 4: *Pre-1990 forest age class frequency distributions based on summary statistics (grey histograms) and a fitted distribution curve (solid line) using a Gaussian function. The 1959 and 1968 data (see Mean Age in Table 1) did not categorise age-classes older than 50 years.*

Characterisation of the age class distributions using the Gini coefficient (G) and Lorenz curve provide a measure of changes in the age-class distribution over time (Figure 4). A forest with equal areas in each age-class will have a G value of zero and a straight line for the Lorenz curve (Figure 5). This uniform age-class distribution can be visualised as a histogram with the same value for each age-class frequency bin. The lower G value and smaller area of the Lorenz curve under the theoretical uniform age distribution line, shown for 1998 in Figure 5, suggest a more uniform age-class distribution when compared with 1968 and 2006.

An important consideration when using G coefficients is that different Lorenz curves can produce similar G values. Therefore, it is important to consider both the G value and mean age-class when considering a nationally-specific reference period for accounting sinks in the future.

The observed decline in gross biomass increment between 1998 and 2020 (Table 2) may be due age-class and/or management legacies. The age-class legacy effect is manifested by the change in the mean age and age-class frequency (as shown in Table 2) and a decline in productivity in younger crops after clearfell. However, a decline in biomass increment may also be associated with premature clearfelling due to a reduction in rotation age (i.e. management legacy, Table 3).

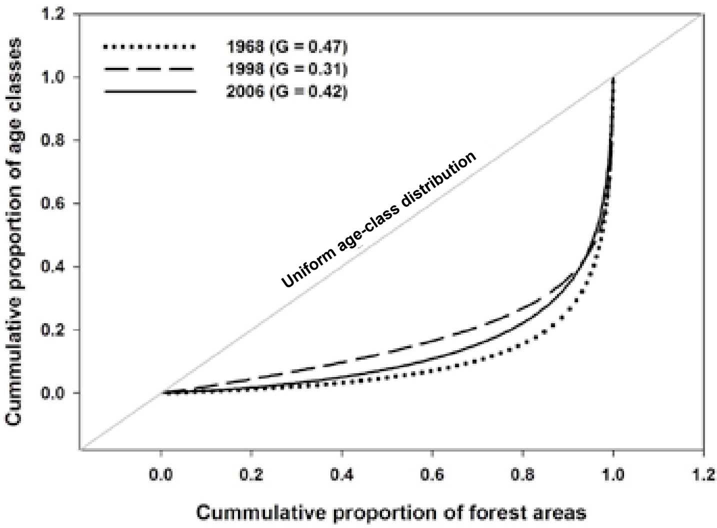

Figure 5: *The Lorenz curve as applied to age-class inequalities across the re-sampled age-class populations for 1968, 1998 and 2006.*

Table 2: *Mean age-class and G values over the pre-1990 forest time series and the potential influence of age-class legacy on biomass productivity.*

Year	Mean age[a] (years)	G coefficient	Gross biomass increment[b] (t C ha^{-1} yr^{-1})
1959	13	0.53	n.d.
1968	15	0.47	n.d.
1979	18	0.43	n.d.
1986	*Missing data*	*Missing data*	*Missing data*
1998	28	0.31	2.9
2006	24	0.42	2.7
2012	22	0.43	2.4
2020	25	0.40	2.4

[a] Mean forest age based on reconstructed age-class distributions using a Gaussian function (see Figure 4).

[b] Gross biomass increment (i.e. biomass increment before harvest removal) was taken from the CARBWARE model outputs based on the total gross biomass increment and representative pre-1990 forest areas.

Management legacy effects

From a productivity perspective, maximum merchantable volume productivity over time is achieved by final harvesting at the age of maximum mean annual volume increment (MMAI). There is evidence of a pre-mature rotation age (i.e. clearfell before MMAI is reached) in the pre-1990 estate (Table 3). This is consistent with the introduction of new harvesting policy in the 1980s following economic analysis undertaken by the Crop Structure Section of the Forest and Wildlife Service Research Branch in 1976 (Henry Phillips, pers. comm.)[7]. Clearfell scheduling is currently based on a commercial rotation age, which is the age at MMAI minus 20% for Sitka spruce, and 30% for Norway spruce and lodgepole pine (Table 3). These species account for over 95% of harvest in pre-1990 forests.

[7] Based on an economic analysis undertaken in 1976-77 by the Crop Structure Section of the Research Branch of the Forest and Wildlife Service, which resulted in the Forest and Wildlife Service issuing an Operational Directive on *Rotation Lengths and Thinning Regimes for Conifers*.

Table 3: *Mean rotation ages of different species from the forecasted sub-compartment and management unit data for the period 2008 to 2020. (Abbreviations: n is the number of compartments, MMAI the maximum mean annual commercial volume increment, n/a not applicable).*

Species		Age (years)		
		-at Forecast rotation	-at commercial rotation	-at MMAI
Lodgepole pine (n = 53)				
	mean	39	40	57
	range	30-86	32-52	45-75
Sitka spruce (n = 156)				
	mean	41	42	52
	range	11-73	33-52	42-65
Norway spruce (n = 17)				
	mean	40	36	51
	range	12-50	31-40	45-57
Other conifers (n = 18)				
	mean	48	n/a	59
	range	10-48		42-75

Harvested volumes from prematurely clearfelled stands represented ca. 30% of the annual harvest in pre-1990 forests between 2000 and 2005. This reduced to ca. 10% for the years 2007 and 2008. However, analysis of projected clearfell data, based on sub-compartment and management unit records, suggest that premature clearfell will account for ca. 35% of the sub-compartments harvested in pre-1990 forests over the period 2008 to 2020.

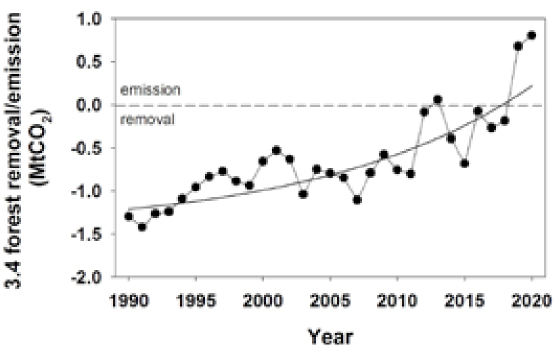

Figure 6: *The total C stock change, excluding harvested wood product storage for all pre-1990 forests (Article 3.4), for the years 1990 to 2020. The solid regression line is included to indicate smoothed trends over time.*

Historic and projected emission/removal for Article 3.4 forests

The historic and projected emission/removal estimates, under current accounting rules (assuming HWP stock change is instantaneous) for the pre-1990 forest, show a marked decline in removals, particularly since ca. 2000 (Figure 6). The pre-1990 forest changes from a net sink of 1.2 Mt CO_2 in 1990 to a net emission of 0.8 Mt CO_2 by 2020.

Analysis of the different C pools suggest the net C stock changes (Figure 6) are primarily associated with age class and management legacy effects (Tables 2 and 3). This is manifested by changes in:

1. an increased harvest with a concomitant decrease in the net biomass increment and
2. a decrease in the deadwood sink (Figure 7).

a) <u>Increment versus harvest</u>

The slight decline in biomass increment net of harvest over the time series is primarily associated with an increase in harvest from pre-1990 forests. The CARBWARE v5 model and the Coillte timber forecast shows that the equivalent harvest from pre-1990 forests increased from 1.6 M m^3 in 1990 to 3.1 M m^3 in 2020 (Anon 2008, Donlan et al. 2012). The smoothed harvest from pre-1990 forests is projected to be 3.1 M m^3 by 2020.

The roundwood harvest per unit of productive forest in pre-1990 forests has increased over the past 20 years. For example, the harvest volume in Article 3.4 forests in 1990 was ca. 1.4 M m^3 from a productive area of 466 kilo-hectares (kha; which includes open areas) compared with a projected harvest of 3.1 M m^3 from an area of 452 kha in 2020. This represents an increased mean harvest from the total productive area from 3.0 m^3 ha^{-1} in 1990, to 6.8 m^3 ha^{-1} in 2020. However, when expressed on the basis of harvested area, the harvest per unit of clearfell would be similar over the time series (ca. 350 m^3 ha^{-1}). This is consistent with the increase in the area of forest replanted following harvest in the Coillte estate, from ca. 4,000 ha in 1990 to 8,000 ha in 2007 (under Irish forest legislation all clearfelled areas must be replanted).

The decline in biomass increment net of harvest (Figure 7) may also be associated with a small decline in gross biomass increment (i.e. before harvest), but to a lesser extent (see Table 2).

b) <u>The deadwood pool harvest residue effect</u>

The decrease in deadwood C stock removals (Figure 7) may be associated with both the age class/management legacy and harvest residue decomposition effects. Figure 8 shows the model output for the net C stock change (including biomass, litter and deadwood pools) of a typical forest type (Sitka spruce, yield class 16 m^3 ha^{-1} yr^{-1}). Symbols with positive values represent losses (or emissions of C) due to harvest as thinnings (T1 and T2), clearfell (CF) and residual decomposition losses associated with harvest residue (HR). Note that the residual C loss of HR following first rotation is due to the decomposition of deadwood, roots and litter. This C loss is carried over to the second rotation for a period of ca. 30 years. The C gains from biomass increment in the second rotation are included in the C budget and there is a net C loss for the first

10 years of the second rotation (Figure 8B).

The carry-over of harvest residue decomposition losses has important implications for the legacy effects in setting a national reference level. This is particularly relevant when there are historical fluctuations in the areas being clearfelled, as is evident from the Coillte replanting records. The replanting records for the Coillte estate show an increase in areas replanted up to 2000, followed by a projected downward trend into the 2012 to 2020 period. For this study it was assumed that the replanting rate mirrored the clearfell trend.

Factoring out legacy and indirect human induced effects

Böttcher et al. (2008) advocate the use of a projected Forest Management reference level to factor out age-class and other management-legacy effects. A possible problem with the concept is that indirect human induced and natural activities are not always excluded from accounting, depending on the models and methodologies included. This is, however, not an issue if the same modelling framework and assumptions (for example, a model such as CARBWARE) are used for both the projected reference level and the reported time series. If different methods are to be used, this may necessitate a technical correction (which is provided for in the current LULUCF negotiation text) to ensure time series consistency. In such cases it may be necessary to factor out indirect human-induced activities, which is difficult unless projection models include functionality for the characterisation of CO_2 fertilisation and N deposition. Few, if any, countries reporting to the UNFCCC have developed models which factor out indirect human induced activities. For example, CARBWARE is an empirical model with no process based functionality to include the effects of climate change or N deposition. Therefore, if a projected Forest Management reference level is compared with observed stock change in the projection period series (which presumably includes indirect and natural effects), there would be no factoring out of natural or indirect

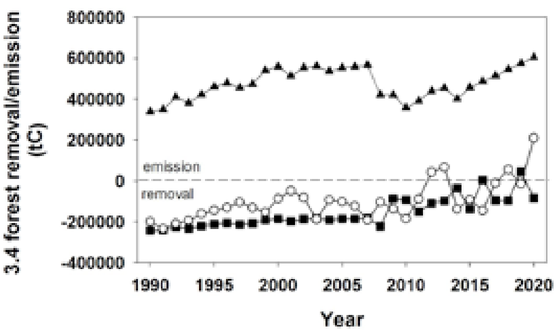

Figure 7: *C stock change of major C pools in pre-1990 (Article 3.4) forest over the years 1990 to 2020. Values represent the flux of the C pools for harvested roundwood (closed triangles, all of which is assumed to be immediately oxidised under current accounting rules), net biomass increment after harvest (open circles) and the deadwood pool (closed squares).*

human-induced activities. This highlights the importance of a provision to allow for a technical correction in order to ensure time-series consistency and that indirect human-induced emissions/removals are factored out for both the reference level and reported time series. Overall, factoring out indirect human induced and natural effects remains a scientific challenge because interactive effects, feedback mechanisms and scaling such effects to the regional level are still poorly characterised (Ainsworth and Long 2005).

Historical adjustment – an approach to deal with age-class legacy
During the period when options to deal with the age-class legacy effect were being discussed in the UNFCCC negotiations, the feasibility of a backward adjustment of the historic time series was explored, so that age-class legacy effects were accounted

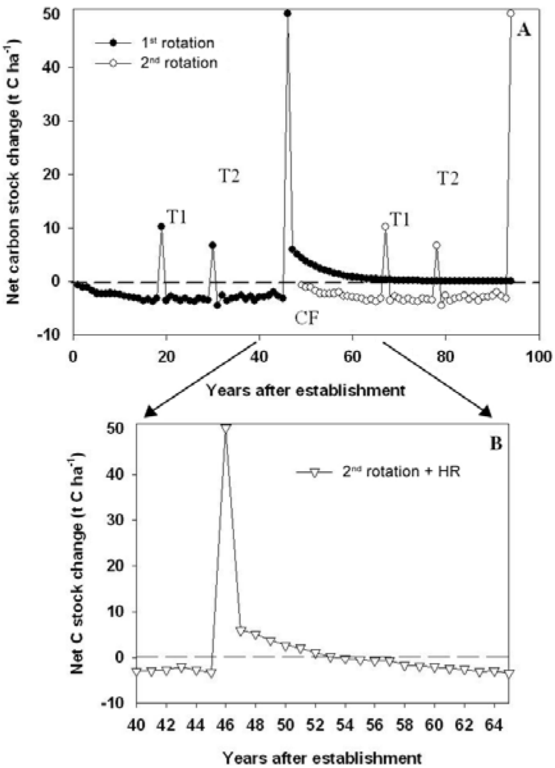

Figure 8: *Estimated net C stock change of a yield class 16 Sitka spruce stand over two rotations (**A**) and the combined effect of harvest residue (HR) decomposition from the first rotation and biomass growth in the second rotation, due to replanting after two years (**B**). T1 and T2 represent thinnings and CF indicates clearfell at maximum mean annual increment (rotation age of maximum roundwood productivity). Positive values represent a loss (emission) of C due to harvest and harvest residue decomposition (HR).*

for, while still fulfilling the criteria set out by the Marrakesh Accords. The advantage of this method is that the traditional net-net accounting methods can then be used for all land-use classes, which should in theory, also exclude indirect human induced and natural effects (see Introduction). The approach aimed at adjusting the historical reference-period values, based on a mean growth increment (before harvest) over the projected time series.

For those years where no age class data were available to derive G coefficients, a linear decline in the coefficient from 0.42 in 2006 to 0.303 in 1998 was assumed (i.e. a decline of 0.013 units per year). Similarly, the mean stand age was assumed to decline by 0.5 years per year between 2006 and 1998. This weighted adjustment, in theory, would only adjust for the relative difference in mean age and age-class distribution, assuming a linear relationship between these variables and mean GI. This historic adjustment approach (Eq. 15, Figure 9) is, however, based on the assumption that only age-class legacy is influencing the increment before harvest, which is not correct since it has been shown that part of the reduction in increment before harvest is also due to premature clearfell (i.e. management legacy). This approach is further limited by the lack of historic age-class data for the entire time series.

<u>Projected Forest Management reference level or forward looking baseline</u>

The projected reference level (referred to as the forward-looking baseline) assumes that the Coillte forecast represents a BAU scenario (see Introduction). Using this approach, the reference level for the second commitment period (2013 to 2020) would be -0.008 M t of CO_2eq[8] per annum (derived from the mean of the projected C stock change from 2013 to 2020 shown in Figure 6). This includes an estimated annual emission of 0.012 M t of CO_2eq from wild fires, which was obtained from the mean annual emission from fires since 1990.

The advantage of this accounting approach is that it provides an incentive/disincentive to undertake activities that increase or decrease either CO_2 sequestration potential or stock change due to varying harvest levels relative to BAU. A disadvantage is that the use of projected data leads to a larger level of uncertainty when compared with historic data. To address this and other issues, the current draft negotiation text includes a proposal to have an asymmetrical cap which would limit credits and debits under this Article to fixed percentages of 1990 emissions.

Implication of different accounting approaches

The implications of proposed Forest Management accounting approaches (Table 4) for the period post-2012 are summarised below:

1. Gross net accounting using a discount rate.
   Although forest management has been capped for CP1 (2008-2012), it is likely that a gross-net approach would be based on a discount (85% was used in the forest commitment period) of net removals (or emissions). This accounting

[8] CO_2 equivalents (eq) include the global warming potential of other gases such as methane (24 times that of CO_2) and nitrous oxide (298 times that of CO_2) all expressed as equivalents of CO_2. Wild fires could result in an emission of both methane and nitrous oxide, in addition to CO_2.

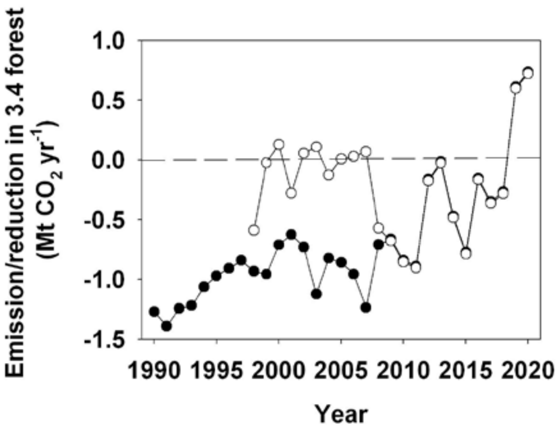

Figure 9: *Historic and projected C stock change in pre-1990 forests (closed circle symbols as shown in Figure 6) and historically adjusted reference period (open circle symbols, see Eq. 7) for the years 1990 to 2020. Note: the adjusted reference time series could only be calculated from 1998 due to missing age class distribution data (see Figure 3 and Table 2).*

framework essentially provides credits for BAU in pre-1990 forests, and when combined with a cap, provides little incentive for climate change mitigation activities in pre-1990 forests that go beyond BAU.

2. Net-net accounting using reference periods 1990-1994 and 2000-2004. The proposed use of a reference level based on a historic period rather than a specific year is intended to counteract inter-annual variability in C stock changes.
3. Net-net accounting with an adjusted reference level from 2000-2004, shown in Figure 9.
4. A projected reference level for the period 2013 to 2020 with a 5% cap on credits and a 10% cap on debits should be adopted.
5. The reference value over the commitment period is calculated using the mean annual C stock change for the reference periods, multiplied by the number of years in the commitment period (assumed to be 8 years, 2013-2020). The potential debit or credit is based on equations 1, 2 and 3 (see Introduction) and excludes RMUs from HWP.

Table 4: *The implications of different Forest Management accounting approaches under Article 3.4, based on historic (unadjusted or adjusted) and projected C stock change trends.*

Reference period	Ref level ($Mt\ CO_2\ yr^{-1}$)	Ref level over period 2013-2020 ($Mt\ CO_2$)	Credits/debit over period ($Mt\ CO_2$[a])
1. Gross-net with an 85% discount[b]			
n.a.	n.a.	n.a.	-0.001
2. Net-net un-adjusted historical time series[c]			
1990-1994	-1.222	-9.776	9.712 (no limit)
2000-2005	-0.776	-6.208	6.144 (no limit)
3. Net-net with weighted adjustment for legacy[c,d]			
1990-1995	n.d.	n.d.	n.d.
2000-2005	-0.022	-0.176	-0.406 (no limit)
4. Forward looking baseline with asymmetrical cap[e]			
2013-2020	-0.008	-0.064	0 (-22.08 to 44.24)

[a] Positive values represent an emission or debit, negative values represent a removal or credit.
[b] Gross-net accounting does not have a reference level (n.a.: not applicable).
[c] Net-net accounting does not normally have a debit or credit cap; therefore there are no limits on potential credits or debits.
[d] There are no data available for a historical adjustment prior to 1998, so the 1990-1994 reference level could not be determined.
[e] The caps are applied as 5% of base year emissions (excluding LULUCF) for credits and 10% for debits (base-year emissions in 1990 were 55.374 Mt CO_2eq excluding LULUCF).

Conclusions and practical implications

Based on the scenario analysis presented in Table 4, it is evident that gross-net accounting with an 85% discount offers little incentive for Ireland to elect Forest Management post-2012. We have also demonstrated that the currently used net-net accounting framework could result in significantly less ambitious targets being set when taking LULUCF into account (debits of 6.1 to 9.7 M t CO_2) over the period 2013-2020. This is clearly related to age-class and management legacy effects from the pre-1990 forest, which affect the current and projected C stock changes (Tables 2 and 3, Figure 6). This should be taken into account in future accounting frameworks.

Factoring-out age class legacy can be done in several ways. The historical adjustment we examined, when combined with net-net accounting, does offer some advantages, but only addresses age-class structure. The option, which is the most effective in removing both the age-class and management-legacy effect, is a projected reference level, based on BAU management policy. Differences between the BAU projections and future C stock change would, therefore, reflect accountable credits or debits arising from additional activities in pre-1990 forests. The inclusion of an asymmetric cap at the proposed levels (5 and 10% of 1990 emissions) provides an incentive for enhanced sequestration through forest management, but also reduces large emission debit risks. For example, accounting using a projected reference level, with an asymmetric cap would allow a national credit in pre-1990 forest of up to 22.08

Mt CO_2 over the period 2013-2020, but at the same time limit potential debits to 44.24 Mt CO_2.

The use of a projected reference level also has the potential advantage of providing the same or a similar incentive basis for all Parties that choose to account for Forest Management in the future.

Factoring out of indirect human induced effects related to elevated CO_2 levels and nitrogen deposition is only addressed (in the formulation of the cap on Forest Management) under the accounting framework for the first commitment period. The proposed projected reference level or a net-net approach with a weighted legacy adjustment could factor out indirect human-induced changes in forest C stocks. The potential ability to use a technical correction, when different models or methods are used for the reference level and reporting time series, is an important proposal to ensure transparency and unbiased accounting of Forest Management in the post-2012 period.

In conclusion, this paper outlines a national approach for factoring out age class and indirect human induced effects using a projected reference level approach. This approach has been subject to international review and was deemed to be in accordance with principals set out in Appendix II of Decision 2/CMP.6. However, these are proxy approaches, given the limited current scientific understanding of indirect human induced effects on current and future forest sinks, in particular the influence of elevated CO_2 and N deposition (Ainsworth and Long 2005, Black et al. 2010). In addition, more research is required to further develop national capacity for reporting Forest Mangement C stock changes. Specific research needs include soil C stock changes (Wellock et al. 2011) and use of remote sensing technologies to estimate changes in forest areas (due to harvesting, deforestation and natural disturbances) at a higher spatial resolution than what is offered using the current national forest inventory.

There are several practical implications from this study, which include:

- The current sequestration of plantation forests is strongly influenced by management practices or policies, which may have occurred a long time ago. For example, historical fluctuations in afforestation rates could result in emissions 50 years later due to age-class shifts.
- Premature harvesting reduces the sequestration potential at the stand and national level.
- Harvesting results in a residual emission from the deadwood pool for ca. 30-years after harvest. Additional harvest of non-timber biomass, such as bundling and stump harvesting, would result in an even higher emission from national forests.

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