Investigating the impact of varying levels of inventory data detail on private sector harvest forecasting

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Abstract

A comparison was made between four methods of generating roundwood production forecasts for private sector forests in Ireland which used varying levels of inventory data as inputs into the production Model. Two methods were based on stand variables: the Irish Dynamic Yield Model (IDYM) method and the General Yield Class (GYC) method. The other two methods were based on site variables used to derive predictions of productivity from climate and map-based data and include a local prediction (LPYC) and a national prediction of yield class (NPYC), the latter the same as that used in the All Ireland Roundwood Production Forecast 2016-2035 (Phillips et al. 2016). To determine the reliability of predictions for an individual stand, field measurements of yield class (GYC) were compared with the predictions of yield class derived using the NPYC and LPYC methods for 52 privately-owned stands of Sitka spruce in the north-west of Ireland. The prediction of yield class using the NPYC method had a low probability of agreement with GYC, with a large bias to under-predict yield class. The LPYC method had a higher probability of agreement and lower bias indicating a better assessment of local productivity. To assess the impact of the various productivity estimates on roundwood production forecasts, separate roundwood forecasts for the period 2016-2035 were generated. The forecast produced using the NPYC method was used as a baseline for comparison purposes. As expected, the under-prediction of yield class using the NPYC method produced the lowest volume production estimate (318,454 m^3) for the forecast period. Both the GYC and LPYC methods resulted in a significant increase in estimated volume production of between 25% and 29% over the baseline. The IDYM method provided the highest estimate of volume production (432,000 m^3) for the forecast period, an increase of 35% over the baseline. The increased output predicted using the IDYM method is explained by the inclusion of stocking and basal area data, which more accurately reflected the increased growing stock of private forests than yield data derived using Forestry Commission yield models based on prescribed management. The increases in productivity associated with the use of LPYC, GYC and IDYM methods had the effect of producing

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shorter rotations and resulted in an increase in the area clearfelled and associated volume production. Perhaps more importantly, the timing of volume production was affected by using more accurate methods to assess productivity (i.e. LPYC, GYC, IDYM), owing to a higher yield-age profile of stands compared to those assessed using the NPYC predictions. The findings point to a possible under-estimation of the productivity for private stands in the All Ireland Roundwood Production Forecast and have implications for the timing of the forecasted volume which could be brought forward by 5 to 6 years. In the absence of field or aerial laser measurement of height and age, the use of the LPYC method is recommended for future private sector roundwood producion forecasts.

Keywords: *Sitka spruce, yield class, forest inventory, yield prediction models.*

Introduction

Roundwood production forecasts have increased in importance in Ireland in recent years and serve to support planning and investment decisions regarding the infrastructure required to mobilise the forest resource. It is estimated that significant increases in timber volume are forecast in the next two decades as a result of increased private sector planting in the late 1980s and 1990s and that the annual Net Realisiable Volume (the volume net of harvest loss) will increase from 3.95 million m^3 in 2016 to 7.86 million m^3 by 2035 (Phillips et al. 2016). The history of volume forecasting in Ireland is relatively short-lived, dating back to the second half of the last century. Forecasts for state-owned forests were first estimated based on a combination of forest inventory information, Forestry Commission yield models (e.g. Bradley et al. 1966, Hamilton and Christie 1971, Edwards and Christie 1981) and a series of simplifying assumptions. With the introduction of computers, the computational aspects of forecasting were greatly improved, and use was made of more complex and robust forecasting models. Today, roundwood production forecasting is based on more complete inventory information, taking account of environmental considerations and forest management constraints, together with improved and more flexible growth and yield models and the use of forest optimisation software.

Forecasting is about predicting the future roundwood output as accurately as possible, given the information available. Roundwood production forecasts require:

(a) data describing the forest resource;
(b) data describing the intentions of owners regarding silvicultural regime, rotation length, thinning frequency and intensity;
(c) forest growth models which can estimate future volumes; and
(d) a forecasting model which incorporates all of the required information and any underlying assumptions, e.g. the sustainability of the forest resource, the replanting of felled stands, the rate at which increases or decreases in forecast production volumes are released to a market, etc.

Information on timber supply and production forecasts for state-owned forests are regularly made available to the processing sector (based on Coillte's inventory and forecast planning system). The basic management unit here is the stand in which growth attributes are recorded (captured from a combination of field survey and remote sensing) at various points in the forest cycle. Coillte's system facilitates local and national level planning and wood production forecasting over both longer and shorter time horizons and the use of forest optimisation software.

Similar detailed information is often not available for the private sector. The first forecast of roundwood production (2001-15) for private sector forests used planting rates and a series of underlying assumptions based on expected yield, together with the Forestry Commission Yield Models (Edwards and Christie 1981), to derive estimates of roundwood production from private sector forests (Gallagher and OCarroll 2001). More recently, there have been advances in the quality of the datasets used and the capacity to forecast wood production from the private sector with the inclusion of spatial data for private forests, and a COFORD-funded private sector "geospatial forecast" was published in 2009 (Phillips et al. 2009). This allowed for the production of higher resolution catchment and regional forecasts to be included in the second national roundwood forecast (Phillips 2011). The main strength of the forecast was that it included species data and stand-based spatial data, which enabled the production of catchment and other scenario-based forecasts utilising the most up-to-date information that was available on private forests at the time. The current All Ireland Roundwood Production Forecast (Phillips et al. 2016) incorporates a number of further refinements including improved forest resource information for private and state-owned forests, an improved national yield class estimation model for private sector forests[1] and the use of forecasting optimisation software for scenario analysis.

The availability of limited inventory data and a series of underlying assumptions governing the choice of yield model, management regimes and forecast rules, mean that the forecast may not be applicable at individual stand level, with implications for the accuracy of the All Ireland Roundwood Production Forecast. While a range of errors can be part of roundwood production forecasting (Forestry Commission 2012), for the private sector element of the forecast the main limitations are primarily:

- incomplete inventory data which are used as an input into the production model;
- limited information on the management intentions of private forest owners, for example, if, when and how a stand is going to be thinned and the rotation length of the stand;
- insuffficent information on the accessibility of private stands.

Inventory information which is insufficient to provide a reliable indication of a

[1] Farrelly, N. 2015. A note on the derivation of yield class for the national forecast dataset. Teagasc, Athenry, Co. Galway (unpublished).

stand's yield class and the selection of an inappropriate growth and yield model for a stand have the greatest potential to introduce estimation errors for forecast volumes. Where inventory data exist, indirect estimates of yield class can be derived for Sitka spruce (*Picea sitchensis* (Bong. Carr.) using site variables for a given stand (e.g. Farrelly 2011). The current All Ireland Roundwood Production Forecast uses such a model to predict the yield class of private stands; however, the accuracy of these predictions at an individual stand level has yet to be determined. In situations where stand level data exists, a direct assessment of yield class is possible and is most suitable for pure and even-aged stands. The precise calculation of yield class requires that a knowledge of the cumulative production (including thinnings) of a stand and that the stand remains in place until its productivity reaches the maximum mean annual volume increment. As this specific information is rarely available, the use of top height and age to calculate General Yield Class has been widely used, as top height and age show a close relationship with cumulative volume production (Edwards and Christie 1981). However General Yield Class may not adequately reflect local volume production as a result of local fertility or environmental conditions (e.g. Gallagher's 1975 study). A further complication of the use of yield class and the Forestry Commission yield tables is that the management is static, in that it assumes a prescribed course of management and deviations from this course of management will result in less reliable growth projections.

Potential to further improve private sector forecasts is possible through the use of detailed inventory data which would allow the use of the Irish Dynamic Yield Models (IDYM) (Broad and Lynch 2005) to provide a more accurate assessment of growth and yield at individual stand level. The models represent a dynamic system to represent forest growth in Ireland which can be used to forecast volume production using top height, basal area, and stocking while allowing considerable flexibility in forest management.

Some opportunity exists to collect harvest data for private stands, perhaps in tandem with the proposed new Forest Management Plan (FMP) (see COFORD 2015), or as part of the application for a felling licence (F. Barrett, Forest Service, pers. comm.). Should such data become available at a stand level, it may represent a better basis for forecasting. In the meantime, it is likely that inventory information will continue to be derived using approximations of stand attribute data. There is also potential to collect tree height and related data using remote sensing (e.g. LIDAR) and for the further refinement of yield model predictions. The use of such methods or predictions together with the selection of the most appropriate yield model may provide acceptable levels of accuracy at individual stand level.

In order to address the varying levels of inventory data detail and management information likely to be available for private sector forests, a study was conducted which compared four different methods for generating roundwood production forecasts for private sector forests. The methods were based on current forecasting procedures used for the All Ireland Roundwood Production Forecast but differ in that they included different measures of stand productivity representative of varying levels of inventory data detail used as inputs in the production model.

Methods

Study area and field data collection

A study area was selected in the northwest of Ireland which covered parts of counties Mayo, Sligo and Roscommon, representative of a large concentration of private forests stands in Ireland (Figure 1). A total of 52 privately-owned stands of pure Sitka spruce (*Picea sitchensis* (Bong.) Carr.). were selected, comprising a total area of 769 ha. Stands were classified as being at the pole to semi-mature development stage (aged between 13 and 26 years), even-aged and uniformly stocked. To derive direct estimates of stand productivity a detailed inventory assessment of stands in the study was conducted. Between six and ten assessment plots were randomly located in each stand for detailed measurement (based on the protocol of Mackie and Mathews 2008). Plot size ranged between 0.01 (for unthinned stands) and 0.02 ha (for thinned stands). In each plot, an inventory protocol was used for assessing merchantable volume where all live trees with a diameter at breast height (DBH) greater than 7 cm were measured using the electronic calipers (Masser excaliper™) according to the protocol of Mackie and Matthews (2008). In each plot, top height (defined as the largest 100 trees ha^{-1} by Edwards and Christie (1981)) was measured as the height (m) of the largest DBH tree or the mean of the top height of the two largest DBH trees within the plot, depending on plot size.

To cover within-stand variability, a target level of precision for DBH accuracy was set to ± 5% which guided the number of plots and trees necessary to maintain accuracy levels using standard statistical formula in the COFORD (2000) timber measurement manual. The total number of trees and the sum of basal area for all trees across plots in a stand were divided by the total area represented by the sample plots to derive stand level stocking and basal area. Mean top height was calculated as the mean of the top height for each sample plot. Age was available from initial planting maps provided by the Forest Service, Department of Agriculture, Food and Marine. For each stand, therefore, the area, age, stems ha^{-1}, top height, quadratic mean DBH and basal area ha^{-1} were available. These data allowed the most detailed assessment of stand productivity and were suitable/sufficient for utilising the Irish Dynamic yield models. This was referred to as the IDYM method.

An additional assessment of stand productivity referred to as the General Yield Class method (GYC) involved deriving the GYC of stands by matching top height

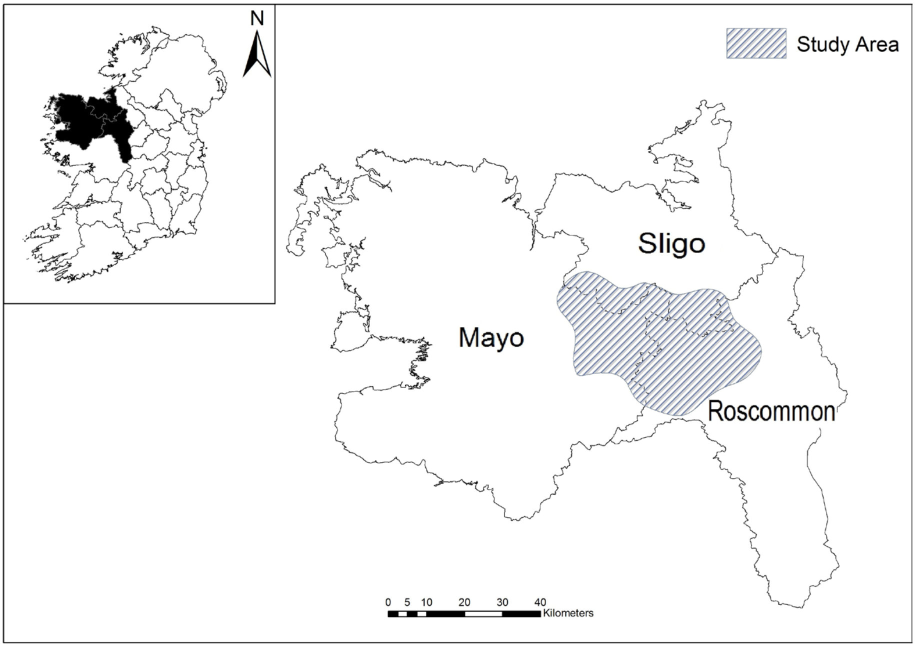

Figure 1: *Location of study area in the northwest of Ireland*.

and age with the appropriate yield class curves for Sitka spruce (Edwards and Christie 1981). To deal with stands where top height or age was outside the range in the Edwards and Christie (1981) models (i.e. yield class >24), a linear relationship was derived between top height at 30 years (THT30) and yield class from Forestry Commission top height data for Sitka spruce (Edwards and Christie 1981) where yield class = 1.28 × THT30 - 3.6 (r^2 = 0.99). A site index (height in metres at an age of 30 years) was calculated for stands using site index curves for Sitka spruce in Ireland (Broad and Lynch 2005) and the relationship between top height and yield class was used to derive the yield class of stands.

To represent situations where no inventory information was available for stands, predictions of yield class were derived using site productivity models (Farrelly et al. 2011, Farrelly 2015). The first prediction referred to as the national prediction of yield class (NPYC) was derived from a model which related yield class to low resolution map-based data describing windspeed, climate zone, soil parent material and management type (whether classed as afforestation or reforestation) to derive a yield class of the stand. The climate and site data were derived from wind speed, climate zone and soil parent material maps (Anon 2003, Farrelly et al. 2009, Gardiner and Radford 1980, Fealy et al. 2008, respectively) arranged in geographic information system (GIS). The second prediction of yield class, referred to as the local prediction of yield class (LPYC) was derived from maps of windspeed, soil parent material and high-resolution Ordnance Survey (1:10,560) maps. The Ordnance Survey maps were used to categorise stands according fertility class (A, B, C and X) based on OCarroll's 1975 classification. This model, owing to the increased resolution of the Ordnance Survey maps representing field-level scale (stand), was somewhat more representative of local site fertility conditions (Farrelly et al. 2011). Therefore, four measures of stand productivity representing varying levels of inventory data detail were available for use in the study as follows (Figure 2).

The first step in the generation of the forecast was to derive the current volume of stands using each of the productivity estimates above. For the IDYM method, the crop parameters relating to age, stem density, top height and basal area were entered directly into the IDYM (via the Growfor interface[2]) to generate stand volume. For the other productivity estimates (GYC, LPYC, NPYC) which only had yield class available, the effect of stand density was accounted for by using a hybrid approach to generating stand volume. Initial growth parameters (i.e. top height, stocking and basal area) were taken from the appropriate Forestry Commission yield table to input into the IDYM and the stand was then grown to its reference age (Figure 2).

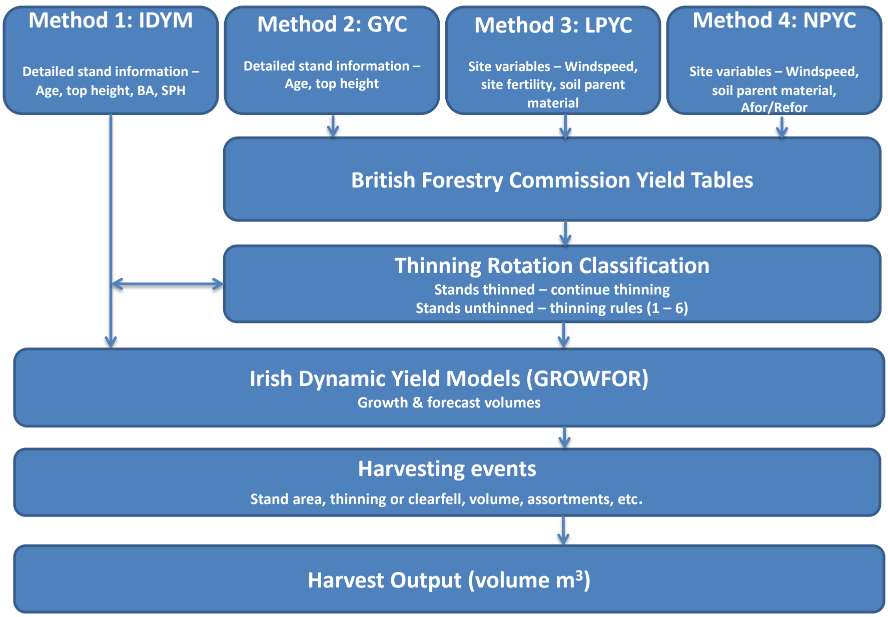

Figure 2: *General overview of the four methods and forecasting methodology used in the study.*

[2] Growfor is the software program which provides the graphic user-interface of the Irish Dynamic Yield Models.

Assigning a thinning and rotation classification to stands

For the methods using yield class estimates (GYC, LPYC, NPYC), stands already thinned (n=17, identified during the field survey), were deemed to be suitable for further thinning treatments. For unthinned stands, whether they were to be thinned or not was based on a series of thinning rules used in the All Ireland Roundwood Production Forecast.

1. If the stand area is ≤4 ha, then no further thinning.
2. Stands had to have a minimum yield class of 16 $m^3ha^{-1}yr^{-1}$ to thin.
3. If the stand age is more than the first thin age plus 2 years and the crop is unthinned, then no thinning.
4. If average wind speed is ≤7 m s^{-1} on stable soils, thin. If mean wind speed ≤6 m s^{-1} on unstable soil, then thin.
5. Access: a combination of area, soil type and distance from nearest county road determine if the crop will be thinned in the model.
6. Thinning prescription: three thinnings on a 4-year cycle removing 50% of yield class.

Spatial data describing windspeed, elevation, soil type and proximity to the nearest county road was used to decide whether stands would be thinned. The application of the thinning rules allowed each stand to be allocated to a thin or a no-thin cohort for each method. For each stand, the age of first thinning and planned rotation age were assigned based on the estimated yield class and the thin status, using the look-up tables used in the All Ireland Roundwood Production Forecast (Table 1). Once the age of first thinning was determined, the timing (forecast year) of each harvesting event was allocated. If the current age of the stand was greater than the age of first thinning, the stands in the thin cohorts were assumed to have already received a first thinning. Similarly, if the current age was greater than the age when a second thinning was due, this thinning was assumed to have taken place. For the IDYM method, a different approach was taken. The number of thinnings that had already taken place were determined based on its yield class-age profile, after which the stands' suitability for further thinning treatments at a given age were assessed by examining the stocking and basal area. A matrix of age by forecast year (2016 to 2035) was constructed to allow planned harvesting events to be allocated to the correct forecast year, and for the cross-checking each method of forecasting (Table 2).

Forecasting Volumes

For the yield class methods (GYC, LPYC, NPYC), a master look-up table based on the yield data used by the forest optimisation software (Remsoft®) in the All Ireland Roundwood Production Forecast was compiled for thinning and clearfell volumes.

Table 1: *Rotation ages for thinned and unthinned stands of Sitka spruce and age of first thinning based on Yield class (after Phillips et al. 2016).*

Yield class	Rotation age (years)		Age of first thinning (years)
	Unthinned	Thinned	
14	43	43	23
16	40	39	22
18	37	36	21
20	34	35	20
22	33	34	19
24	31	32	18
26	28	30	17
28	27	29	16
30	26	28	15
32	26	28	15

Gross stand volumes were reduced to net volumes to allow for harvest losses, which varied with harvest type, and for attrition losses, the values of which were based on a further look-up table again derived from the Remsoft yield data (Phillips et al. 2016). The net volumes for each planned harvesting event were then multiplied by the respective stand area and assigned to the specific forecast year based on the dates indicated in Table 2. These data were then summed to provide an estimate of forecast volume for the period 2016 to 2035 (inclusive) for each dataset. Finally, the clearfell and thinning areas by thinning number were summed to provide an indication of the percentages of stands that were thinned and clearfelled.

To estimate the forecast volumes for the IDYM method, a different approach was again required. Crop parameters relating to age, stocking, top height and basal area were entered into the IDYM. The no-thin cohort of stands were grown until the planned clearfell year (based on the yield class) and the gross volume, mean tree and basal area were recorded. For the thinning cohort of the IDYM method, a view was taken as to whether a planned thinning event had in fact occurred prior to the date of measurement (2016) based on the plot parameters, and a decision made whether a future thinning was appropriate. Using the age/forecast year matrix, thinnings were then removed using the same gross volumes as for the All Ireland Roundwood Production Forecast. Thinned stands were then grown on to the planned rotation age. Volumes and volume assortments were recorded for each harvesting event. Thinning and clearfell volumes were adjusted for harvest losses in line with the All Ireland Roundwood Production Forecast. Clearfell volumes were adjusted to take account of attrition losses, again using the same values from the Remsoft yield data for all stands. Finally, the thinning and clearfell volumes were allocated to the specific forecast year based on their current age and the age at the planned harvest event.

Table 2: *Example of matrix used to determine harvest year for a sample of stands (colours represent thinning operation). Colour code: green = 1st thin; blue = 2nd thin; pink = 3rd thin; yellow = clearfell.*

Site no.	Thinning age (years)	Clearfell age (years)	LYC	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
1,726	21	36	**18**	26	27	28	29	30	31	32	33	34	35	36
476	18	32	**24**	17	18	19	20	21	22	23	24	25	26	27
583	18	32	**24**	20	21	22	23	24	25	26	27	28	29	30
591	18	32	**24**	24	25	26	27	28	29	30	31	32	0	1
599	18	32	**24**	20	21	22	23	24	25	26	27	28	29	30
625	18	32	**24**	24	25	26	27	28	29	30	31	32	0	1
675	18	32	**24**	21	22	23	24	25	26	27	28	29	30	31
965	18	32	**24**	21	22	23	24	25	26	27	28	29	30	31
1,684	18	32	**24**	19	20	21	22	23	24	25	26	27	28	29
1,686	18	32	**24**	22	23	24	25	26	27	28	29	30	31	32
678	18	32	**25**	21	22	23	24	25	26	27	28	29	30	31
3,162	17	30	**26**	20	21	22	23	24	25	26	27	28	29	30
3,163	17	30	**26**	24	25	26	27	28	29	30	0	1	2	3
3,165	17	30	**26**	24	25	26	27	28	29	30	0	1	2	3
3,166	17	30	**26**	24	25	26	27	28	29	30	0	1	2	3
818	16	29	**28**	19	20	21	22	23	24	25	26	27	28	29
832	16	29	**28**	19	20	21	22	23	24	25	26	27	28	29

Analysis

The first part of the study sought to validate the relability of the productivity estimates for each stand and whether indirect measures were representative of direct measures of productivity. The GYC estimate for stands was compared with the NPYC estimates used in the All Ireland Roundwood Production Forecast and the LPYC estimate using the agreement statistic methods in SAS (SAS/STAT, 2018). Agreement statistics use a TDI (total deviation index) as a measure of how well two sets of data agree with each other (for them to be tolerable substitutions for each other). The analysis calculates the 95% coverage probability (CP) that the TDI will be less than 3.0 (i.e. a difference of 3 m^3 between the two data sets at 95% confidence). Therefore, high probability value (>0.8) would suggest a close agreement between data.

To determine the impact of the different stand yield class estimates (GYC, LPYC) on roundwood production forecasts for the study area, we compared the forecast output from each method to the NPYC which is used in the current All Ireland Roundwood Production Forecast. To demonstrate the potential of having more detailed inventory information the IDYM method was included for further comparison. All methods used the period 2016 to 2035, the same timescale used in the All Ireland Roundwood Production Forecast.

Results

The reliability of the productivity estimate

The mean GYC of stands in the study was 25.7 m^3 ha^{-1} yr^{-1}, which was well above the national average reported for the species for private sector stands of 21.0 m^3 ha^{-1} yr^{-1} (Farrelly et al. 2009). On average, productivity in thinned and unthinned stands was similar; site index at 30 years was 22.9 and 22.8, respectively (Table 3). A comparison between the NPYC and the GYC indicated a low coverage probability (CP) of 0.21, indicating a lack of agreement between the data. The relative bias value of 2.24 is large relative to 1, indicating that the measure of agreement is very low, owing to the large difference between NPYC and GYC (Table 4, Figure 3a). A comparison between the LPYC and the GYC indicated a higher coverage probability of 0.61, and the bias was much smaller (0.18), indicating a better agreement between the data. However, the LPYC and the GYC measures were not within 3 m^3 ha^{-1} yr^{-1} of each other (i.e. when a TDI value of 3 was used); the LPYC model demonstrated full agreement with the GYC at the 95% level when the TDI value was raised to 6.8 (to be within 6.8 m^3 ha^{-1} yr^{-1} of each other) (Table 4, Figure 3b).

Table 3: *Summary of field data (range, mean and standard deviation) for thinned and unthinned Sitka spruce stands used in the study.*

Characteristic	Range	Mean	SD
Unthinned stands (n = 35, 442 ha)			
Area (ha)	1.7-47.2	12.6	9.4
Age (years)	13-24	17.8	3.1
Top height (m)	8.4-18.7	13.2	2.8
Mean DBH (cm)	10-21	15.6	2.8
Stocking (stems ha^{-1})	1,500-3,911	2,377	486
Basal area ($m^2 ha^{-1}$)	20.2-60.1	43.0	10.3
Site index @ 30 years (m)	15.4-26.1	22.8	2.5
General yield class (GYC $m^3 ha^{-1} yr^{-1}$)	16-32	25.7[a]	3.4
Local prediction of yield class (LPYC)	18-28	23.8[b]	2.2
National prediction of yield class (NPYC)	16-22	19.5[c]	2.4
Thinned stands (n = 17, 327 ha)			
Area (ha)	3.6-47.2	19.2	13.5
Age (years)	17-26	21.5	2.5
Top height (m)	13.0-18.4	16.3	1.6
Mean DBH (cm)	16-23	19.6	2.3
Stocking (stems ha^{-1})	810-1,899	1,233	349
Basal area ($m^2 ha^{-1}$)	21.6-56.8	35.5	9.1
Site index @ 30 years (m)	17.4-26.4	22.9	2.4
General yield class (GYC $m^3 ha^{-1} yr^{-1}$)	18-30	24.9[a]	2.9
Local prediction of yield class (LPYC)	18-28	24.6[a]	2.2
National prediction of yield class (NPYC)	16-24	19.3[b]	2.1

[a, b, c] Letters indicate significant differences (P <0.01).

Table 4: *Agreement statistics for GYC vs. NPYCC and GYC vs. LPYC (n = 52).*

Statistics	Precision coefficient	Accuracy coefficient	TDI	CP	RBS[a]
GYC vs. NPYC					
Estimate	-0.0391	0.2676	14.4[b]	0.21	2.24
95% Conf. Limit	-0.2674	0.2012	16.3	0.15	
Allowance			3.0	0.95	
GYC vs. LPYC					
Estimate	0.3878	0.8266	6.8[b]	0.61	0.18
95% Conf. Limit	0.1724	0.6816	7.9	0.53	
Allowance			3.0	0.95	

[a] The relative bias squared (RBS) must be less than 1 or 8 for a coverage probability (CP) of 0.9 or 0.8, respectively, in order for the approximated Total Deviation Index (TDI) to be valid. Otherwise, the TDI estimate is conservative depending on the RBS value.

[b] TDI value that will give 95% confidence.

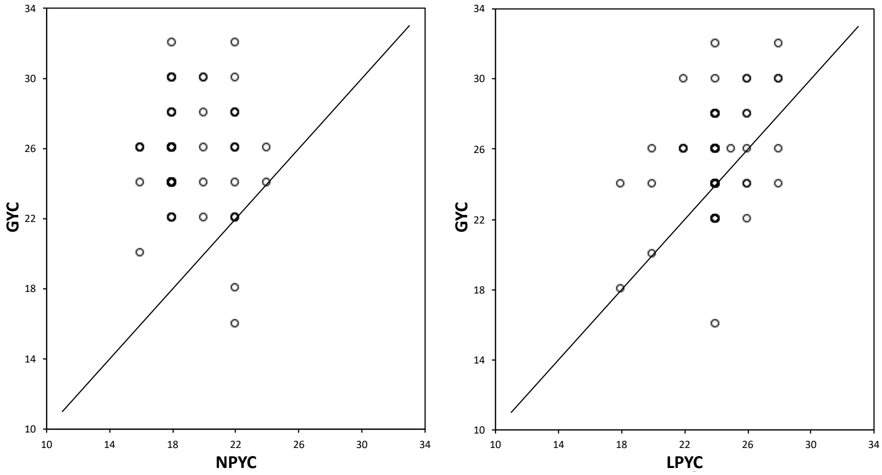

Figure 3: *(a) Scatter plot of GYC (m^3 ha^{-1} yr^{-1}) versus NPYC (m^3 ha^{-1} yr^{-1}), showing bias for under-prediction of yield class where the majority of points are above the line of perfect agreement (y=x) and (b) GYC and LPYC showing somewhat closer agreement and lower tendency for under-prediction.*

Comparison of the forecast methods

The forecast using the NPYC (baseline) method resulted in a total net forecast volume production of 318,000 m^3, comprising 28,000 m^3 from thinnings and 290,000 m^3 from clearfell over the period 2016 to 2035 (Table 5). A total of 351 ha was deemed to be suitable for thinning, representing 46% of the total area, which is greater than the estimated national average of 31% to 40% in the All Ireland Roundwood Production Forecast, when wind speed or soil type, elevation and wind zone were factored in to estimate stability (Phillips et al. 2016). Clearfell was forecasted to occur on 695 ha or 90% of the area and averaged 418 m^3 ha^{-1}.

When GYC and the LPYC were used as estimates of productivity to generate the forecast, the resulting increase in yield class for both methods led to an overall increase in the net forecasted volume production between 25% and 29%, to 399,060 m^3 and 410,030 m^3 respectively, over the period 2016 to 2035 (Figure 3). In both methods the clearfell

Table 5: *Harvest area and volume by harvest type for the four different methods.*

Method	Area (ha)	Clearfell area (ha)	Clearfell volume (m^3 ha^{-1})	1st thin (ha)	2nd thin (ha)	3rd thin (ha)	Thin volume (m^3 ha^{-1})
NPYC	769.3	694.8	418	145.5	277.7	350.6	80
LPYC	769.3	755.5	514	3.8	208.0	326.9	65
GYC	769.3	753.1	502	3.8	187.5	326.9	65
IDYM	769.3	753.1	547	-	121.4	326.9	52

volume increased by over 30%, to 388,541 m^3 and 377,959 m^3 respectively, compared with the baseline. Both methods resulted in an increased clearfell volume (514 m^3 ha^{-1} and 502 m^3 ha^{-1} compared with 418 m^3 ha^{-1} for the baseline). There is a reduction in the thinning volume by 25% and 23% for the GYC and LPYC methods as many areas are assumed to have received their first and second thinning due to their yield class-age profile, with the area subject to thinning reducing (Table 4).

The forecast using the IDYM method resulted in an increase in forecast roundwood production of 35%, largely owing to the large increase in clearfell volume which increased by 42% to 412,234 m^3 compared with the baseline method of 290,380 m^3 (Table 4). Increased roundwood production was due to higher yield class combined with shorter rotations compared to the baseline method. This was reflected in an increase in the area clearfelled (753 ha compared with 695 ha) and a corresponding increase in the volume of clearfell (547 m^3 ha^{-1} compared with 418 m^3 ha^{-1}). There was a reduction in forecast thinning volume of 40% compared to the baseline, as many of the areas are assumed to have already received their first and second thinnings due to their yield class-age profile, thus the area of first and second thinnings was reduced by 220 ha (Table 5).

The timing of the forecast volume was also affected by the choice of method; the bulk of the harvest volume was due in the last quarter or at the end of the forecast period for the LPYC and the NPYC methods, compared to the middle of the forecast period for the GYC and IDYM methods, as the overall increase in yield class resulted in shorter rotations (Figure 4).

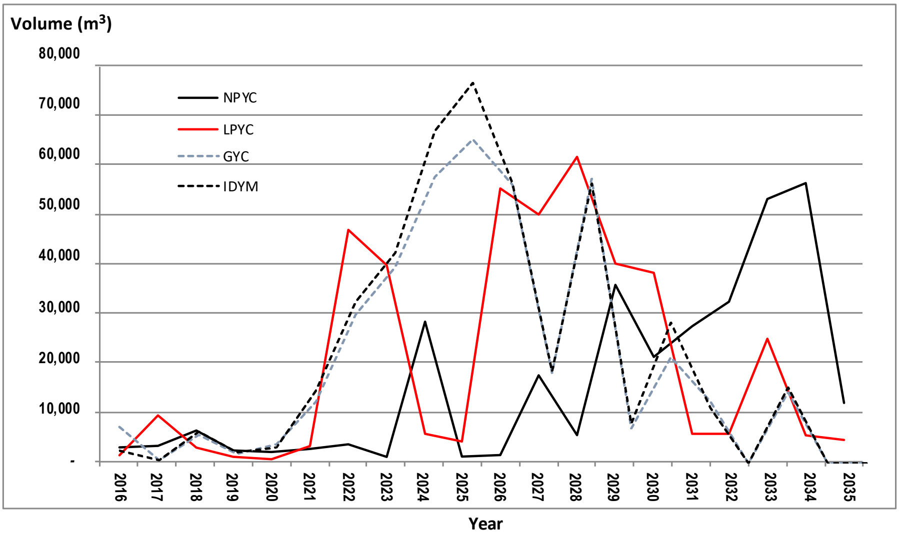

Figure 4: *Annual forecast volumes 2016-2035 for each of the four different methods (NPYC, LPYC, GYC and IDYM).*

Discussion

There was poor agreement between GYC and the yield class derived using the NPYC. Closer agreement was found between GYC and the LPYC. The impact of using more reliable estimates of stand productivity achieved using the LPYC and the GYC methods was to increase the output and bring forward the forecast of volume production. More accurate national private sector roundwood production forecasts can be achieved by adopting the LPYC prediction of yield class, which has been shown to give a closer approximation of productivity for individual stands. Utilising the LPYC model for the next All Ireland Roundwood Production Forecast would require the attribution of fertility class, available from Ordnance Survey Ireland (OSI) 6-inch or 25-inch maps for private stands. The OSI maps have been digitised for the entire country and are readily availabe in a GIS.

The NPYC used for the All Ireland Roundwood Production Forecast in 2016, developed using map-based variables, showed a weaker relationship with GYC. While the prediction model was developed to include productive stands (range in yield class from 4 to 34[3]), the range in overall prediction for stands in this study was limited (YC 16-24) and thus was disappointing. The LPYC prediction was a considerable improvement and was sufficiently capable of predicting the yield class of more productive stands as encountered in the study (range in predictions for stands were between yield classes 18 and 28 $m^3ha^{-1}yr^{-1}$). The poorer performance of the NPYC method was less accurate as it uses less well resolved site classification variables available at lower resolution (soil parent material, scale 1:50,000) compared to the LPYC (scale 1:10,560) and thus the NPYC method lacks sufficient explanatory power (variables were less able to predict the yield class of more productive stands). The LPYC method, which uses fertility class derived from Ordnance Survey map ornament, showed better predictive power as the variables used by the model were better at explaining the variability in fertility, with a high proportion of productive stands falling into fertility class A according to OCarroll (1975), as well as yield at a stand level. The LPYC method may offer a sufficient level of accuracy given the limited data that exist for private stands in Ireland and it would be impossible for a model to fully predict yield class. For all stands combined the LPYC model underestimated the yield class of stands with the mean error of prediction being less than one yield class (i.e. 1.4 m^3 ha^{-1} yr^{-1}), and differences between GYC and LPYC indicated that 95% of stands fell within ±6.75 m^3 ha^{-1} yr^{-1}, with a bias to under-predict the yield class of productive stands.

Given that a roundwood production forecast is so dependent on stand productivity, it is not surprising that forecast volume production using the LPYC method is close

[3] Farrelly, N. 2015. A Note on the Derivation of Yield Class for the National Forecast Dataset. Teagasc, Athenry, Co. Galway (unpublished).

to that predicted from the GYC method, with harvest area and volume by harvest type similar for both methods. An increase in the forecasted volume production for the LPYC method is attributable to an over-prediction of yield class (8.0 m^3 ha^{-1} yr^{-1}) for a single stand of 10.8 ha. Despite similarities in roundwood production forecasts, differences in the timing of the forecast were apparent (Figure 3), with the bulk of the forecasted volume output due in the third quarter of the forecast period for the LPYC, compared with the middle of the forecast period for the GYC method. Compared with the NPYC baseline, all other methods showed volume output occurring earlier than expected due primarily to a better productivity estimate being available for the production model which had a major effect on the timing of thinnings and clearfells, which were all brought forward to an earlier date and the average production per harvesting event was increased. The impact of the more accurate estimate of yield class was a higher yield class-age profile, which resulted in lower forecasted volumes for first and second thinnings and higher volumes for subsequent thinnings. This increase in yield of the LPYC, GYC and IDYM methods over the NPYC method resulted in an increase in the area suitable for harvest and a corresponding increase in volume coming from clearfell operations. The net result was that stands had shorter rotations and earlier clearfells, resulting in significant increases in forecasted volume production over the forecast period (2016-2035).

The IDYM method resulted in the greatest increase in forecasted volume production (35%) over the NPYC method. The increased stand volume was due to the use of detailed inventory data or data which perhaps more accurately reflected local volume production. It showed an increase over all methods. The increase over the LPYC method was largely due to the inclusion of actual stocking and basal area, which more accurately captured local volume production of stands compared with data derived from yield tables used in the other methods. A difference of 45 m^3 ha^{-1}, on average, was apparent in clearfell volumes when calculated using the IDYM method compared with the GYC method. This was due primarily to stands being overstocked and having more basal area for a given yield class (which assumed a prescribed management, stocking and basal area), thus the IDYM provides increased flexibility to provide a more accurate assessment of volume production for a wider range of stands with variable growing stock. While the assumption is that the IDYM estimate of volume production is the most accurate, it is unknown how the model would perform in highly productive stands of Sitka spruce, and the growth and thinning function have yet to be validated. While the availability of detailed inventory data allows for the adoption of the IDYM for forecasting purposes, another advantage afforded is the more accurate assessment of the suitability of the stand for thinning based on stocking and basal area information or whether thinning should be delayed for the growing stock to increase. As many of the stands assessed in this study were outside the range of data used to produce the IDYM (Broad and Lynch 2005), predictions for high yield class need to be used with caution.

The proportion of stands that were found to be thinned is of interest. Some 352 ha were thinned, representing 46% of the total area, compared with an estimated national average of 31% to 40% in the All Ireland Roundwood Production Forecast (Phillips et al. 2016). The higher estimate of thinning from the study can be partially explained by the higher yield classes observed. Other factors such as age profile, forest owner preferences and information provision, local market conditions and lower windthrow risk may also have impacted on the decision to thin or not.

Conclusions and recommendations

For a range of private stands of Sitka spruce in the north-west of Ireland, the use of the NPYC estimate of productivity, as in the All Ireland Roundwood Production Forecast, resulted in a significant underestimation of yield class; on average, predictions were in the order of 6 m^3 ha^{-1} yr^{-1} less when compared with the GYC estimate. The LPYC showed better levels of agreement with GYC with 80% of predictions within ± 4 m^3 ha^{-1} yr^{-1}. In the absence of observed yield information or better models, the use of the LPYC is recommended for the next All Ireland Roundwood Production Forecast to increase the reliability of the productivity estimate for private stands.

The study was useful in demonstrating the effect of high levels of stand productivity on the timing of forecast volumes, which may need to be brought forward by 5 to 6 years to adequately reflect the impact of more productive stands. It is likely that the more accurate measurement of yield class, may give a better indication of the timing of forecast volume output as judged from the GYC and IDYM methods. Given the interest in aerial laser scanning (i.e. LIDAR), potential exists to determine the yield class of stands based on tree heights obtained from scans, which may facilitate more accurate estimation of productivity, in turn facilitating a better assessment of timing of forecast volume output.

It is likely that more detailed inventory data (stocking and basal area or DBH) and the use of IDYM will result in more accurate estimates of local volume production and increase the overall accuracy of forecasts, however, costs may be prohibitive to capture sufficient data from private forests. On the other hand, there is potential to capture data from the revised forest management plans associated with the Forest Service's grant application and felling licence procedures and this could be a valuable source of data for private sector forecasts. Despite the small sample size, the proportion of private crops in receipt of thinning may require further attention as the number of stands in receipt of a thinning in the sample was significantly higher than in the All Ireland Roundwood Production Forecast.

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