Volume production patterns in six downy birch stands in Ireland

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Abstract

Six well-stocked, unthinned downy birch (*Betula pubescens* (Ehrh.)) stands in Cos Wexford, Laois, Wicklow, Offaly and Westmeath were selected for study. A total of 100 sample trees were felled at the six sites. Tree ring data were collected from a total of 1333 tree discs. Using the ring data the historic growth patterns of the six stands were reconstructed, examined and analysed. Local volume equations (volume/basal area lines) expressing the relationship between sample tree over-bark volume (to tip) and basal area were fit to data from two 0.04 ha plots at each site. These were used to determine per ha over-bark standing volume estimates.

For well-stocked, unthinned even-aged stands of downy birch the period of maximum radial growth occurred between the ages of 5 and 20 years. The fastest growing tree achieved a diameter of 25 cm in 32 years. Maximum height growth occurred before the trees were twenty years old; fast growing trees achieved a height growth of more than 1 m yr^{-1} during this period. The results showed that a well-stocked, unthinned downy birch stand could achieve a standing volume of 203 m^3 ha^{-1} in 42 years. Comparison with Forestry Commission yield models showed that stands of downy birch in Ireland may achieve a potential yield class of 8 and, given the appropriate thinning regime, total recovered volume production could possibly be raised to that equivalent with yield class 10.

Keywords: *Betula pubescens* (Ehrh.), downy birch, mean annual increment, mean periodic increment, volume production patterns, tree ring analysis.

Introduction

Birch is one of the most common native woodland trees in Ireland. However, its potential for commercial wood production is often ignored, because existing birch woodlands are often poorly stocked and are generally comprised trees of poor form. Birch has a poor reputation amongst foresters, with the result that many existing birch stands have suffered neglect. Interest in native tree species such as silver birch (*Betula pendula* (Roth)) and downy birch (*Betula pubescens* (Ehrh.)) is now growing. There has been increasing pressure to diversify the range of species in the national forest estate and, in particular, to increase the proportion of native broadleaved species. A growing emphasis is also being placed on the need to preserve and extend existing semi-natural woodland, of which birch is a major constituent.

Aside from the problems of poor stem form, birch has many attributes considered advantageous in a forest tree species, e.g. rapid growth, ease of regeneration, ability to grow on a range of site types, self-pruning and relatively short rotation lengths (Evans 1984).

To date research on birch in Ireland has been limited. Little is known about the abundance or distribution of the two species (silver and downy birch), the quality of the birch resource or the growth performance of existing stands. Those provenance trials that have been laid down have been small in scale and of poor experimental design, and they

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have not yielded any pertinent information on the performance of the Irish birch (O'Dowd 1998). The consequent lack of quantitative data relating to height growth, diameter growth and volume increment of birch in this country is of particular concern.

To this end a study was initiated in 1998 with the aim of examining the growth potential of birch in Ireland. Historic patterns of radial growth at breast height, height growth and volume growth of selected birch stands were examined using stem analysis. We focus in this paper on a comparison of historic volume increment patterns between six stands.

Literature review

Taxonomy of birch

Birch (*Betula* spp.) is an important and diverse deciduous tree genus of the family Betulaceae. About 60 species of the genus occur in the northern hemisphere (Savill 1991). Three species are native to Great Britain and Ireland: silver birch (*Betula pendula* (Roth) or *Betula verrucosa* (Ehrh.)), downy birch (*Betula pubescens* (Ehrh.)) and dwarf birch (*Betula nana* L.). Of these three species, only silver and downy birch are now extant in Ireland. Dwarf birch disappeared from Ireland and lowland Britain during the transition from the last glaciation to the present interglacial (Godwin 1975). In Britain two sub-species of downy birch have been recognised (Figure 1): sub-species *pubescens* is found in lowland and valley locations while ssp. *odorata* is a shrubbier tree of bog and mountain (Clapham *et al.* 1981). In continental Europe three sub-species of downy birch (*Betula pubescens*) have been recognised: *pubescens*, *carpatica* and *tortuosa*.

History and ecology of birch in Ireland

Birch dominated the Irish landscape about 11,000-10,000 BP (Nelson and Walsh 1993), at the end of the most recent ice age, but went into decline thereafter. *Betula* woodland was succeeded by *Corylus-Pinus* and finally by mixed *Ulmus-Quercus* woodland which had covered much of the land by 8000 BP (Mitchell and Ryan 1998). Atkinson (1992) summarised the history of birch species in the British Isles and reported that birch forest was still present at 9000-7000 BP, but in central and western Ireland was giving way to pine. In the Atlantic period (6000-5000 BP) the extent of birch woodland was reduced and in the period 5000-2500 BP, birch receded further in central and eastern parts of Ireland.

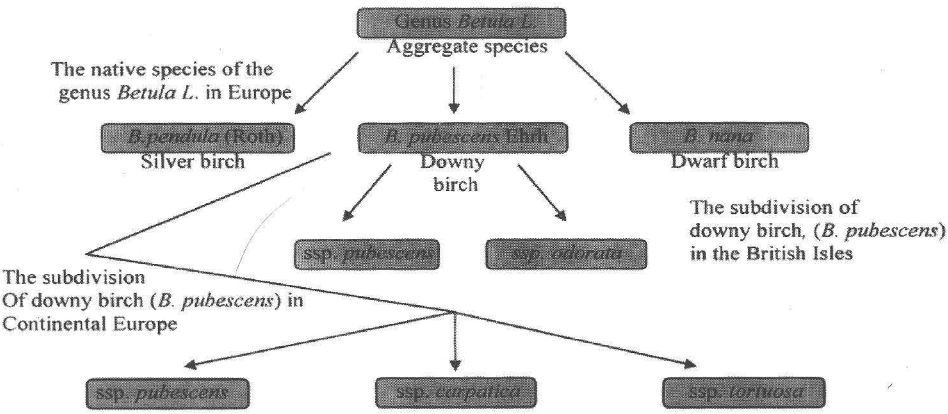

Figure 1: *The nomenclature of European birch (after Brown 1991).*

Rackham (1980) noted that in the last hundred years in England, birch had become one of the commonest trees both of ancient woodland and of secondary woods on the site of heaths, fens and in plantations. A similar pattern of birch colonisation and development is also likely to have occurred in Ireland.

Keogh (1987) indicated that there were some 5,000 ha of birch woodland in Ireland (9% of the total broadleaf resource), although no records existed of the relative abundance of the two different species.

Today birch woods and small groups of trees are common in many parts of Ireland on bog margins, on cutaway (Jones and Farrell 2000) and on clearfelled sites. In most cases they are seral stages to oak or ash woodland and, except where they are on sites of former woodland, are characterised by a rather impoverished flora (Cross 1987).

Yield of birch

In Britain, it is generally agreed that a yield class (YC) of 6 m^3 ha^{-1} yr^{-1} is above average for birch (Brown 1991). Savill (1991) maintains that a maximum yield of 7 m^3 ha^{-1} yr^{-1} may be obtained on the best sites. Current annual volume increment culminates at around 15 to 30 years, while maximum mean annual increment is generally achieved at an age of 40 to 50 years. The highest growth rates in Europe appear to occur in Poland (Philip 1978).

In England potential cumulative production on good sites after 40 years (estimated to be close to the age of maximum mean annual increment at YC 8) is around 170-200 m^3 ha^{-1} (Cameron 1996). In Finland, stands originating from genetically improved planting stock can reach the final target size in as little as 40 years and produce over 400 m^3 ha^{-1} (equivalent to a YC of at least 10) (Vihera-Aarnio 1994). Niemisto (1996) studied silver birch plantations in Finland and found that stands achieved a total yield of 230 m^3 ha^{-1} on average (nearly 400 m^3 ha^{-1} maximum) at 30 years of age.

It is generally recognised in Europe that the growth and yield of silver birch is greater than that of downy birch. Seaman (1994) noted that downy birch is known to grow more slowly than silver birch although the differences are difficult to quantify owing to interactions with site. Koski (1991) reported that downy birch is ecologically more flexible than silver birch, but from a forestry point of view is less productive. Worrell (1999) reported that silver birch grows approximately 20-100% faster than downy birch depending on the site. In both Finland and Sweden, studies have shown that silver birch gives a 15-20% greater volume yield than downy birch (Frivold and Mielikaninen 1991). Braastad (1985) reported a 1.5 m^3 ha^{-1} yr^{-1} higher potential yield of silver birch than downy birch. Yield models constructed by Koivisto (1959) show that, on similar site classes, the total yield of silver birch over a period of 60 years is over 100 m^3 ha^{-1} greater than that of downy birch.

Materials and methods

Selection of stands

Stands with a minimum area of 1 ha, having a stocking greater than 80% of full (normal stocking) and with an age within the range of 15 to 60 years were selected as candidate study sites. Thirty-three stands, including a number that were privately owned, were visited. Six stands, which were considered to meet the selection criteria, were selected for inclusion in the study (Table 1). No distinction was made between stands originating from natural regeneration, planted stands, or stands comprised of the two forms of regeneration.

Table 1: *Study sites - location, stand and site characteristics, and sample plot data.*

Site description	*Site 1*	*Site 2*	*Site 3*	*Site 4*	*Site 5*	*Site 6*
Coillte forest	Bunclody	Portlaoise	Private	Portlaoise	Kinnitty	Lough Owel
County	Wexford	Laois	Wicklow	Laois	Offaly	Westmeath
Aspect	SE	NW	SW	NW	S	W
Elevation (m)	180	120	150	60	50	80
Exposure	Exposed	Moderate	Sheltered	Sheltered	Moderate	Moderate
Soil	Brown pod-zolic	Raised bog	Grey-brown podzolic	Gley	Raised bog	Fen peat
Stand area (ha)	2.3	1.0	2.0	2.9	2.3	4.8
Form of regeneration	Planted	Mixed	Natural	Planted	Planted	Planted
% birch	100	97	81	100	97	100
Birch stocking (trees ha^{-1})	2750	3263	975	1513	1763	1413
Stand age[1] (yr)	34	21-22	49-52	41-43	32-38	58-68
No. sample trees	14	14	20	18	17	17
No. sample discs	181	162	286	271	223	210
Basal area (m^2 ha^{-1})	33	19	29	32	31	22
Mean dbh (cm)	12.4	8.6	19.4	16.3	14.8	14.0
Total volume ob[2] (m^3 ha^{-1})	172	100	170	203	191	115
Annualised volume (m^3 yr^{-1})	5.06	4.76	3.40	4.83	5.46	1.85
Top height (m)	14.03	12.83	17.08	16.40	14.86	14.63

Field measurements and sample tree analysis

Two 0.04 ha plots were randomly located in each of the six stands. Care was taken to avoid locating the plots near the edge of the selected stands. A complete tally was made of all stems within the plots. The diameter at breast height (dbh) of all living stems (greater than or equal to 7 cm) was recorded to the nearest millimetre. The sample tree selection method followed a procedure adopted by Borowski (1954) and Turnbull (1958). In one of the two plots on each site, the trees were classified into 20 mm (2 cm) diameter classes. The average basal area in each diameter class was calculated. Two trees of average basal area from each diameter class were located within the plot. (It was assumed that the selected sample trees had volume increments typical of their diameter class.) Where the average dbh did not correspond to an actual tree diameter within a given diameter class, trees with a diameter nearest to the average were selected. In instances where only one tree was recorded for a given diameter class, only this tree was selected as a representative sample tree.

1 Age or age range determined from sample tree ring counts

2 Over-bark

One hundred sample trees were felled in all. Tree ring data were collected from 1333 sample tree discs. The discs (2-3 cm thick) were cut were cut at the stump and at 1 m intervals along the main stem of the selected sample trees, up to top diameter of 2-3 cm. A disc was also taken from each tree at breast height. Disc sections were labelled according to the position (stem length) they were taken at on the main stem.

Discs were dried, sanded and prepared for stem analysis. The WinDENDRO system, comprising a specially designed software package and computer linked digital scanner, was the main tool used in capturing and calculating and ring width measurements from sample tree disk sections.

Height/age curves for the felled sample trees were calculated using Carmean's (1972) method of height estimation in stem analysis, including Newberry's (1991) adjustment. Sample tree volume under-bark (ub) to tip was calculated using the ring width and height data (calculated using Carmean's algorithm) from discs taken at fixed lengths (intervals of 1 m) along the main stem of the sample trees. A detailed account of the procedures adopted for field measurements, sample tree selection, sample preparation, stem analysis and sample tree height and volume growth calculations is given in Barrett (2000).

A linear model (i.e. a volume/basal area line) expressing the relationship between sample tree volume over-bark (ob) to tip and basal area was produced based on the sample trees in the two 0.04 ha plots at each site. These local volume equations were used to predict the total over-bark standing volume.

Determination of volume production and increment patterns

The historic patterns of under-bark volume production, mean annual increment (MAI) and mean (5-year) periodic increment (MPI) were calculated and plotted for each sample tree. Mean periodic increment instead of CAI (current annual increment) was used as it smoothes out the fluctuations that occur where annual growth rates are used. Historic patterns of under-bark volume production were calculated for each diameter class. Graphs depicting the under-bark volume production, MAI and MPI, for each of the diameter classes represented at each site, were constructed. Weighted curves describing the under-bark volume production and volume increment (MAI and MPI) for each of the 0.04 ha study plots were also constructed. These weighted curves were derived by multiplying the number of trees in a given diameter class, in the relevant study plot, by the average volume production values obtained for the two representative trees selected in that diameter class. The under-bark volumes for all diameter classes were summed to determine plot volume at 5-year intervals and MAI and MPI for each plot were then calculated. The weighted under-bark volume increment curves were used to summarise the historic pattern of under-bark volume production and increment for each stand. Over-bark, total standing volume estimates were determined based on the output of the site-specific volume/basal area equations. Confidence limits for the volume estimates were also determined.

In this paper we focus on a comparison between the six sites in the historical volume production and increment patterns and of the total standing volume estimates.

Results

Study sites/stands

All six stands included in the study contained trees with morphological characteristics commonly associated with downy birch. The test devised by Lungren *et al.* (1995) was used to make a conclusive determination of species. As no precipitate of platyphylloside was formed for any of the sample trees tested it was concluded that all stands consisted of downy birch.

Mean annual and mean periodic increment patterns

Site 1: Tombrick, Co Wexford

Mean annual increment and MPI were calculated and plotted for the 0.04 ha study plot at site 1 (Figure 2). Mean periodic increment culminated at approximately year 27, while mean annual increment slowed to almost negligible levels after 30 years. The level of current annual increment will fall below that of mean annual increment at approximately 35 years when the latter will reach a maximum of approximately 4.75 m^3 ha^{-1} yr^{-1} (or 0.19 m^3 $plot^{-1}$ yr^{-1}).

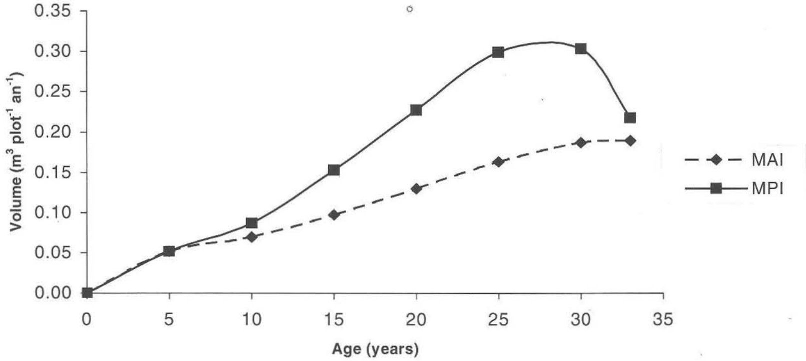

Figure 2: *SITE 1 - mean annual (MAI) and mean periodic (MPI) volume increment patterns.*

Site 2: Colt, Co Laois

Mean annual increment and mean periodic increment for the 0.04 ha study plot at Colt were calculated and plotted (Figure 3). Both mean annual and mean periodic increment (at 3.75 and 7.5 m^3 ha^{-1} yr^{-1} respectively) were still increasing after 21 years growth. Site 2 had the highest stocking level of the six sites, with 3263 trees ha^{-1}.

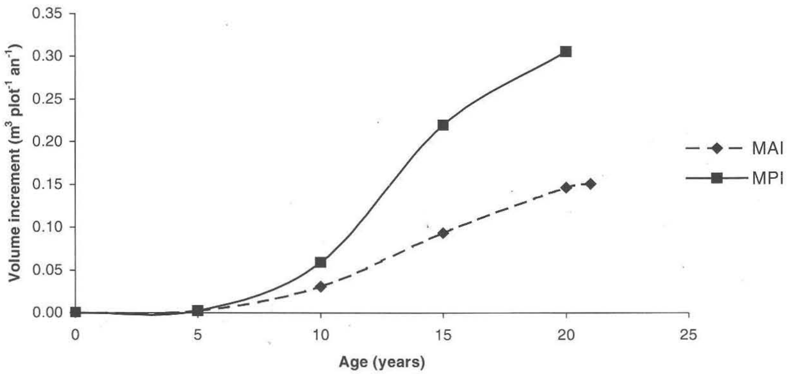

Figure 3: *SITE 2 - Mean annual (MAI) and mean periodic (MPI) volume increment patterns.*

Site 3: Croneybyrne, Co Wicklow

Mean periodic increment culminated at 35 years (Figure 4). There was a temporary decrease in plot MPI at year 30. Mean annual increment was still slowly increasing after 48 years. Culmination of mean annual increment is likely to occur within the next five years at an approximate level of 3.00 m^3 ha^{-1} yr^{-1} (or 0.12 m^3 $plot^{-1}$ yr^{-1}).

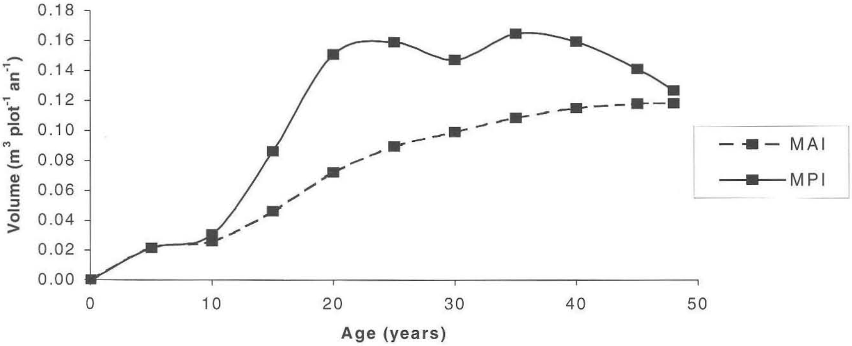

Figure 4: *SITE 3 - Mean annual (MAI) and mean periodic (MPI) volume increment patterns.*

Site 4: Togher, Co Laois

Maximum mean periodic increment for the plot occurred at approximately year 23. Mean annual increment culminated at year 35 (Figure 5). It appears that MPI will be equal to MAI at approximately 41 years, at an approximate level of 4.87 m^3 ha^{-1} yr^{-1} (or 0.195 m^3 $plot^{-1}$ yr^{-1}).

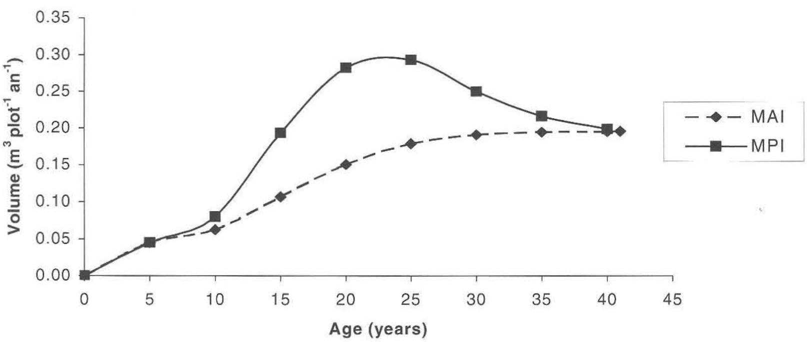

Figure 5: *SITE 4 - mean annual (MAI) and mean periodic (MPI) volume increment patterns.*

Site 5: Falsk, Co Offaly

Mean annual volume increment and MPI were determined to age 32 (the age of the youngest tree on the plot) (Figure 6). Both MAI (at 4.38 m^3 ha^{-1} yr^{-1}) and MPI (at 7.00 m^3 ha^{-1} yr^{-1}) were still increasing after 32 years. A temporary dip in the pattern of MPI was evident at 25 years, corresponding to similar occurrences in most of the diameter classes present in the stand.

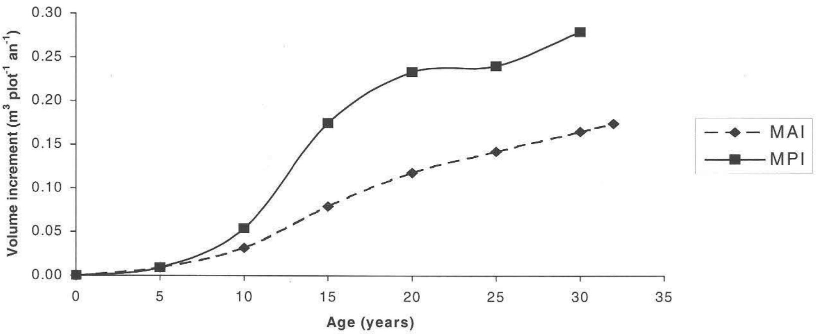

Figure 6: *SITE 5 - Mean annual (MAI) and mean periodic (MPI) volume increment patterns.*

Site 6: Cloonagh, Co Westmeath

Mean periodic increment culminated at 2.93 m^3 ha^{-1} yr^{-1} at 55 years (Figure 7). Mean annual increment was still increasing after 58 years. The assumption of a linear growth pattern in trees in the suppressed diameter classes (8-10 cm and 10-12 cm) introduced a slight distortion in the plotted MAI and MPI curves up until approximately 15 years, similar to those in the curves for sites 1, 3 and 4.

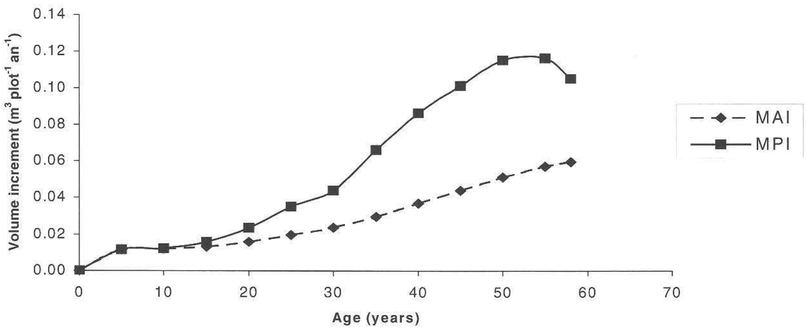

Figure 7: *Site 6 - Mean annual (MAI) and mean periodic (MPI) volume increment patterns.*

Under-bark volume production patterns

Curves of weighted under-bark volume production at 5-year intervals were calculated based on the tree ring analysis data (Figure 8). Birch growing at site 4 reached the highest volume production at 200.0 m^3 ha^{-1} (or 8.0 m^3 $plot^{-1}$) after 41 years. The production of the birch growing at site 6 at 87.5 m^3 ha^{-1} (or 3.5 m^3 $plot^{-1}$) after 58 years was the lowest of the stands examined.

The varying stocking densities and ages of the six stands (Table 1) resulted in confounding of site productivity and stocking. As a result, direct comparison of the six sites based on the historical patterns of volume production may not be truly indicative of potential site productivity.

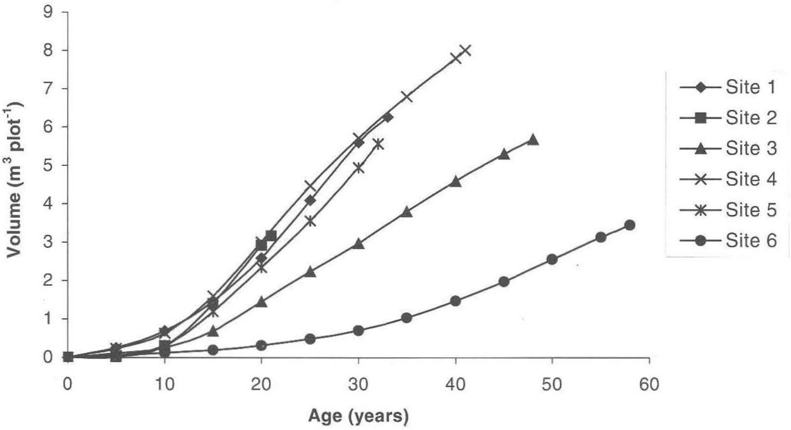

Figure 8: *Under-bark volume production patterns for the six sites, based on tree ring analysis.*

Over-bark standing volume estimation

Volume/basal area equations

A linear model (i.e. a volume/basal area line) expressing the relationship between sample tree over-bark volume (to tip) and basal area was developed based on the sample trees selected and felled in the 0.04 ha plots at each site. These local volume equations were used to predict the total over-bark standing volume (to tip).

A strong positive linear relationship between over-bark volume and basal area was evident across the range of diameter classes sampled. Regression analysis was used to express this relationship for each site (Table 2). The form of the regression equation was:

$$volume = a + b\ BA$$

where, volume = total stem volume to tip (m^3),
BA = basal area (m^2),
a and b are regression coefficients.

The inclusion of an outlying volume value for one tree in the analysis for site 4 resulted in a poorer correlation between sample tree volume and basal area than the values found for the other sites.

Table 2: *Regression coefficients and R^2 values for the volume/basal area relationships for the six sites.*

Site	*a*	*b*	R^2
1. Tombrick	-0.0040	5.5320	0.9803
2. Colt	-0.0038	5.8765	0.9732
3. Croneybyrne	-0.0054	6.0859	0.9713
4. Togher	0.0040	6.2031	0.8942
5. Falsk	0.0023	6.1336	0.9803
6. Cloonagh	-0.0094	5.8960	0.9643

Total volume estimates

The volume / basal area equations were used to derive total plot and per ha over-bark volume estimates for each site. Basal area was calculated for each of the trees recorded in the two 0.04 ha study plots at each site. Volume per tree was calculated by substituting the basal area for each tree into the volume/basal area equation for the site. Tree, plot and per ha volume estimates and associated 95% confidence intervals were then determined (Table.3).

Table 3: *Standing volume estimates and confidence limits obtained using the volume/basal area equations, for each of the six sites.*

Site	*Predicted standing volume*	*95% confidence limit*	
		Lower	*Upper*
		m^3 ha^{-1}	
1. Tombrick	172.49	118.29	226.74
2. Colt	99.73	46.99	152.41
3. Croneybyrne	170.19	124.59	215.80
4. Togher	203.00	98.26	307.73
5. Falsk	191.19	144.46	237.90
6. Cloonagh	114.59	51.70	177.49

Discussion

The objective of the study was to examine the growth potential of birch in Ireland. The growth patterns, in terms of volume increment and total volume production, of selected birch stands were examined and contrasted in detail, using stem analysis.

Volume increment patterns

Examination of the patterns of volume increment revealed that culmination of mean periodic increment (MPI) occurred after 27 years for site 1, after 35 years for site 3, after 23 years for site 4 and after 55 years for site 6. The levels of MPI were still increasing at sites 2 and 5 after 20 and 30 years respectively. Mean annual increment (MAI) became almost constant after 30 years at site 1, after 45 years at site 3 and after 35 years at site 4. MAI was still increasing at sites 2, 5 and 6 after 21, 32 and 58 years respectively. A temporary fall-off in the level of MPI was evident at site 3 and site 5 after 25 and 30 years respectively. This may have been caused by intermittent waterlogging or flooding, combined with the effects of exposure.

Under-bark volume production patterns

A comparison of the historical patterns of under-bark volume production revealed that the under-bark volume production patterns at sites 1, 2, 4 and 5 were very similar. The rate of volume production was increasing at site 1 to 30 years, at site 2 to 20 years, at site 3 to 35 years, at site 4 to 25 years and at site 6 to 55 years. After these points the rate of volume production began to decrease. The rate of volume production at site 5 was still increasing after 32 years of stand growth. The highest rate of volume growth occurred at site 5 between the ages of 30 and 32 years.

Over-bark total standing volume estimation

As expected, there was a strong positive correlation between sample tree basal area and (over-bark) tree volume at all sites (i.e. R^2 greater than or equal to 0.96 for sites 1, 2, 3, 5, and 6 and 0.89 for site 4). The volume/basal area equations used to estimate plot and per ha standing volumes showed that over-bark standing volume estimates ranged from a high of 203 m^3 ha^{-1} for site 4 to a low of 100 m^3 ha^{-1} for site 2 (Table 3). Annualised standing volume production (derived by dividing the estimated standing volume by the average age of sample trees for each site) ranged from a high of 5.46 m^3 ha^{-1} yr^{-1} for site 5 to a low of 1.85 m^3 ha^{-1} yr^{-1} for site 6 (Table 1). However, a direct comparison of total standing volume at the 6 sites may not give a true picture of site productivity because of the lack of stand management, varying stand ages and varying stocking densities.

Comparison of total volume production with Forestry Commission yield models

A detailed comparison of the patterns of volume production found at the six study sites with the patterns of volume production indicated by the Forestry Commission (FC) yield models has not been carried out for three main reasons. First, the volume production values presented in the FC yield models are over-bark volume values. The volume production values for the stands included in this study, calculated using the stem analysis method, are under-bark. Second, the per ha volume values presented in the FC yield models are to 7 cm top diameter, or to the point at which no main stem is distinguishable, whichever comes first. The volume growth of trees in this study was calculated to the tip of the tree. Third, the characteristics of the stands included in this study deviated significantly from the particular treatment regimes set out in the FC models (i.e. the thinning regime and stocking rates), so that direct comparisons of the patterns of volume production were not valid. However, despite these discrepancies, it does appear that total volume production in (unthinned) birch stands in Ireland is very similar to the total volume (i.e. the volume of the main crop and the thinnings) for crops of similar yield class as presented in the FC yield tables. Assuming that significant mortality has occurred due to a lack of thinning, it would appear that the total volume production of Irish stands could exceed the corresponding values in the FC yield tables.

Conclusions and recommendations

This study has successfully demonstrated the usefulness of stem analysis as a technique for determining the past growth history of stands and trees where records are lacking. The results showed that for well stocked, unthinned, even-aged stands of downy birch, the period of maximum radial growth occurred during the period from 5 to 20 years of age. The fastest growing tree was capable of achieving a diameter of 25 cm in 32 years. Maximum height growth occurred before 20 years and fast growing trees achieved a height growth of more than 1 m per year during this period. However, the lack of management, in particular the lack of adequate thinning, may have resulted in excessive crown competition and consequently reduced diameter growth in all of the stands included in this study.

The results showed that a well-stocked, unthinned stand of downy birch achieved a standing volume of 203 m^3 ha^{-1} in 42 years (site 4). Annualised volume production reached 5.46 m^3 ha^{-1} yr^{-1} in a 35-year-old stand (site 5). While some of the stands included had not reached the age of maximum mean annual increment, comparison with the FC yield models showed that stands of downy birch can achieve a YC of 8 (m^3 ha^{-1} yr^{-1}). Given the appropriate thinning regime, the total harvested volume production could potentially be raised to a level equivalent with YC 10, assuming that these regimes would allow for the recovery of significant amounts of volume currently lost due to high mortality rates in the overstocked stands. As this study represented only a preliminary investigation into the volume production of a small number of (unmanaged) birch stands, further research on the growth and yield of birch in this country is necessary. In particular, there is a need for a yield model, more specific to and more appropriate for the birch stands and site conditions found in this country.

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