Forest Research

Summary of FR Seed Origin Trials on grand fir (*Abies grandis* Lindl.)

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The Research Agency of the
Forestry Commission

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Front cover pictures: Grand fir in the experiment Mathrafal 6 in Wales. Of the 36 seed origins at this site, 25 were ≥GYC24 and the lowest was GYC18; the site is a brown earth with 1000 mm rainfall a year.

Contents

Executive summary

In a recent review of research, grand fir (*Abies grandis* Lindl.) was classed as a *secondary species*, i.e. in the past it has been planted on a small scale but has potential for future wider use (Kerr and Jinks, 2015). To ensure the potential of the species is realised there needs to be a scientific basis for future choices of seed origin. Present guidance on seed origins is to favour those from coastal Washington (Forest Research, 2021) based on earlier published results (Samuel, 1996).

In this project seven grand fir seed origin experiments were reassessed and analysed after 40 years to ensure these recommendations are still valid.

The main findings were:

1. Grand fir is a highly productive forest tree and achieved GYC 14-30 on the sites studied, which had widely varying soils, rainfall and temperature.
2. The recommendation for provenance on the FR webpage is that 'provenances from coastal Washington should be preferred'. Based on the results of this study it is suggested that this could be revised to 'provenances from coastal Washington should be preferred; if these are not available then material from coastal British Columbia or coastal Oregon has been shown to perform well in Britain'.
3. More work is also required to provide an objective basis to understand the timber quality of grand fir. At present it has a poor reputation and this is one of the main constraints to it being planted more widely.

1.0 Introduction

Until recently grand fir was not seen as having a major role as a timber species in Britain as the strength properties of the timber compare unfavourably with Sitka spruce and it was thought to be very specific in the site types on which it would perform well. However, the challenges of climate change and tree health have changed the agenda from comparing all conifer species against Sitka spruce to actively examining the best species options for diversification. Grand fir is clearly a good alternative on many sites to Sitka spruce (Aldhous and Low, 1974; Jinks, 2017) and deserves much greater attention to its silvicultural and timber properties.

This report focusses on seed origin variation of grand fir to update the summary information presented by Lines (1987), Samuel (1996) and on the Forest Research (FR) species and provenance webpages (Forest Research, 2021), which is reproduced below.

Extract from Lines (1987) on grand fir

'Recommendations

1. Origins from Region 1 (Olympic Peninsula and the Puget Sound) have grown uniformly well on all sites. Within this Region, individual seedlots from Elwha, Louella and Sequim are outstanding.
2. Excellent height growth characterised the two seedlots from the S Oregon coast (Region 9). However, these flush early and they have suffered some die-back on exposed sites and damage has also been reported on these from the Continent.
3. Vancouver Island seed origins (Region 7) are somewhat slower-growing and they are also rather early in flushing. They have the advantage that their use is well proven in Britain, e.g. the stand of Yield Class 34 at Dunkeld is from Campbell Lake, Vancouver Island.
4. On current evidence, all other regions (apart from 8) are not recommended. Regions 4 and 5 in particular should be avoided.'

Extract from Samuel (1996) on grand fir

'Seed sources from Zone 1 in Washington should be the primary choice for grand fir for general use in Britain. […] The other coastal zones in British Columbia and Oregon (7 and 9), whilst performing well, still show no advantage over Zone 1 material.'

Forest Research (FR) species and provenance webpages

'Provenances from coastal Washington should be preferred.'

1.1 Objectives of study

In 1979 a series of 10 experiments were established to examine the effects of seed origin on growth and yield of grand fir in Britain (Samuel, 1996); seven of these experiments were reassessed in 2019/20. The objectives of this study are:

1. To examine growth of grand fir on contrasting sites throughout Britain using seed origin experiments that were planted in 1979.

2. To compare the growth of grand fir seed collections from its native range with one provenance from Scotland and another from Denmark.

3. To make suggestions for further work on grand fir.

2.0 Seed origin variation in grand fir

2.1 Experiments

The planting material for the majority of the experiments described was the 33 origins of grand fir collected by the International Union of Forest Research Organizations (IUFRO) from British Columbia, Washington, Oregon and Idaho in 1976 and 1978 (Fletcher and Barner, 1978). In addition to the 33 IUFRO collections three other treatments were included in the trials: (1) seed collected from Hagsholm forest in Denmark which Samuel (1996) considers the parent material was from coastal Washington; (2) a commercial seedlot collected in Craigvinean, Scotland for which the parental material was collected from coastal British Columbia; (3) a commercial seedlot collected from Louella on the coast of Washington.

A decision was taken to establish a series of seed origin experiments in 1979, which resulted in trials at 10 sites (Lines, 1987). For this study, seven of the of the initial sites were judged to be 'assessable' (Alice Holt 292, Brendon 35, Inchnacardoch 184, Mathrafal 6, Speymouth 36, Thetford 201, York 2) (Figure 1 in Appendix 1). Due to plant supply problems not all seed origins were planted at each site and therefore the numbers were Alice Holt 292 [20], Brendon 35 [31], Inchnacardoch 184 [36], Mathrafal 6 [36], Speymouth 36 [34], Thetford 201 [31], York 2 [36] (Table 1).

The sites covered a wide geographical range and also had varying rainfall (550-1270 mm yr^{-1}), temperate (1203-1776 day degrees), soil nutrient regimes (very poor to rich) and soil moisture regimes (moderately dry to wet); five of the experiments were planted on free-draining mineral soils and two were on surface water gleys (Table 2). Good establishment practice was used at each of the sites and only a small amount of beating-up was required. In the interval between the measurement at year 15 and the most recent assessment the experiments at Brendon, Speymouth (rack only), Thetford and York had been thinned but the others had not.

For each of the seed origins information was available from the experiment plan on latitude, longitude and altitude.

2.2 Assessments and analyses

2.2.1 Assessments

The seven sites were assessed between December 2019 and October 2020[1]. Each site was assessed using the same protocol:

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[1] There were some delays at Brendon and York due to Covid-19

1. The diameter at breast height (DBH) of each tree;

2. The total height of the two largest DBH trees per plot (an estimate of top height; in some cases this was a single tree as the plots were small);

3. The form of each live tree was scored using the system: 1 = single, straight clear stem and leader ('potentially excellent timber tree'); 2 = single stem and leader but some kinks in main stem and/or heavy branching ('potential timber tree'); and 3 = neither 1 nor 2 ('candidate to remove in early thinning').

The mean of the height measurements for each seed origin at each site was taken as an estimate of top height and from this an assessment of General Yield Class (GYC) was made using the top height-age models for grand fir in Matthews *et al*. (2013).

Each of the sites had been assessed at years 10 and 15 but not all the raw data could be located. Year 10 height data were summarised by Fletcher and Samuel (1990) and analysed; survival data at year 10 were available from Mathrafal, Speymouth, Thetford and York, for other sites the year 15 data were used but are labelled 'year 10' for convenience.

2.2.2 Effects of seed origin and site

In this study data from the 37 treatments were analysed to answer the question: in which region of the Pacific Northwest (PNW) should seed collections be focussed considering growth conditions in Britain? The 37 seed origins were grouped into 9 regions mainly using their geographical locations but also considering other factors such as distance from the coast and rainfall; these were the same groupings as used by Samuel (1996) (see Appendix 1) except that the interior regions 3 and 5 were merged and the material from Denmark was assigned treated as a separate region, because of uncertainty about its seed origin.

All seven experiments had three randomised blocks with 25 tree square plots. In the analysis height and survival after 10 years and height, diameter and form data after 40 years were analysed. The response variables height and diameter were analysed by linear mixed models using the method of residual maximum likelihood (REML). The form scores and survival were analysed by generalised linear mixed models (GLMM), fitting a binomial error distribution and logit link function with the dispersion parameter estimated as part of the model-fitting process.

The structure of the data for modelling was that there were seven experiments (sites) each had three blocks (blocks) and the 37 seed origins (seed origins) were treated as samples of the nine seed regions (regions) within which they were located as described in (Table 1). In each model, the effects of sites, regions, and their interaction were defined as fixed effects (constant + site + region + site.region). The random effects were blocks within sites and seed origins within regions (site.block + region.seed origins). All statistical analyses were undertaken using Genstat 17 (Payne *et al*., 2009).

2.3 Results: seed origin and site

2.3.1 Survival at year 10

- This was generally high (>80%) for all regions except for one (9 – coast of southern Oregon) and two of the seven sites (Brendon [79.3%] and Inchnacardoch [60%]) (Table 3).
- Analysis showed that there were significant differences for region, site and the interaction of these two factors; interestingly the two highest survivals from the Pacific Northwest were for regions 2 and 6, which are the eastern side of the coastal range of grand fir (see Figure 1 in Appendix 1).

2.3.2 Mean height at year 10

- Analysis showed that heights were significantly different between the regions, between sites, and the interaction between the two factors. The coastal regions 1 and 9 had the tallest trees and the shortest ones were inland areas (regions 3/5, 4 and 6) (Table 4).
- The seed origins from Denmark (Region 10) were ranked second tallest at year 10 but there is some uncertainty about the origin of this provenance.
- Heights were largest at Alice Holt, Brendon and York.

2.3.3 Top height and GYC

- After 40 years, top height of the seed origins ranged between 20.30 m (Dump Creek, Inchnacardoch) and 33.9 m (Salmon River, York) (Table 1). The estimates of top height were used to give an indication of GYC and these ranged between 14 and 30, with the most productive sites being Alice Holt, Brendon and York and the least productive Thetford, Speymouth and Inchnacardoch (Table 5).
- Analysis showed that region and site were both significant and the most productive regions were those from the coastal areas of Washington, British Columbia and Oregon (regions 1,7,8,9); the inland area (regions 3/5, 4 and 6) were much less productive (Table 5).
- There were significant differences between the sites with Alice Holt, Brendon and York being superior to other four sites (Table 5).

2.3.4 Form score

- Analysis showed there were significant differences between regions, sites and the interaction between these two factors. Interestingly, the regions with the best mean form score were the inland and coastal areas of Oregon (regions 4,6,8,9), this being the southern part of the native range of grand fir.

2.4 Discussion and conclusions

2.4.1 Seed origins

1. The most comprehensive previous analyses of these experiments was carried out by Fletcher and Samuel (1990) on the 6 and 10 year data and Samuel (1996) on the 15 year data. The main findings from Samuel (1996) are reproduced on page 5 and support the present text on the FR webpages recommending seed from coastal Washington (Region 1) as being the best seed origin. In addition, both of the analyses also indicated that material from coastal British Columbia (Region 7) and coastal Oregon (Region 9) also performed well.

2. The results reported here, 25 years after the last analysis, broadly support the recommendations based on the earlier analyses. The main refinement is that after 40 years all the coastal areas, i.e. Regions, 1, 7, 8 and 9 performed well in terms of height growth and stem form.

3. The experiments included two provenances from northern Europe. The first (74(2002)) from Craigvinean was included in Region 7 in the analysis as the evidence for its origin was strong. The second from Denmark was treated as a separate Region (10); Samuel (1996) believed it to have originated from Region 7. As would be expected based on their seed origins, both provenances performed well and provide good evidence that future work on seed origins of grand fir should include home collected material as a major component.

4. The present recommendation on the FR species and provenance webpage is that 'provenances from coastal Washington should be preferred'. Based on the results of this study it is suggested that this could be revised to be 'provenances from coastal Washington should be preferred; if these are not available then material from coastal British Columbia or coastal Oregon has been shown to perform well in Britain'.

2.4.2 Silviculture

1. The experiments have demonstrated that grand fir is a highly productive forest tree in Britain and achieved GYC 14-30 on seven sheltered sites (DAMS 11-13) with varying soils, rainfall and temperature. This finding supports the thoughts of Samuel (1996) that acceptable rates of growth of grand fir can be obtained on a wide range of sites in Britain. This has been verified by the analysis of Jinks (2017).

2. One of the main reasons why grand fir has not been widely planted as a forest tree are that its timber quality has a poor reputation, it is prone to drought crack and can be sensitive to exposure and pollution. More work is required to provide an objective basis for these concerns. For example, trees from the slower growing

Regions in this study may have superior basic density and produce better quality timber. A study by Bennuah (1992) on two of the seed origin experiments described here confirmed the expected relationship between diameter growth rate and wood density (faster growth produced lower density). However, there were clear instances of individual seed origins that grew quickly having higher density and this is worthy of further study.

3.0 Tables and Figures

Table 1: Summary of the grand fir seed origin locations and GYC** at the experiment sites

				Top height (m) and GYC						
Seed origin	Location	Region	State	Alice Holt	Brendon	Inch.	Math.	Speymouth	Thetford	York
12001	Buck Creek, Darrington	1	WA	33.3	32.3	27.3	32.7	28.8	30.1	30.9
12002	Tulalip, Everett	1	WA	32	31.8	25.7	30.8	26.7	30.4	30.6
12003	Indian Creek, Elwha	1	WA	31.5	32.3	27.1	32	29	30.9	30.1
12004	Gardiner, Sequim	1	WA	32	30.8	27	31.8	29.4	31.5	31.3
12005	Bear Mountain, Louella-Blyn	1	WA	29.8	31.9	25.3	30	27.8	29.8	29.9
12049	Shelton (4km SW)	1	WA	*	33.6	26.2	30.7	29.1	30.2	32.7
12051	Rainbow Falls Park (12km NE Pe Ell)	1	WA	*	30.8	26.4	29.4	27.3	28.3	33.5
74(7973)5	Louella (Commercial)	1	WA	*	*	27.8	31.8	27.7	*	30.4
12006	Eagle Creek, Leavanworth	2	WA	32.5	28.4	22.5	27.2	27.4	28.4	29.2
12007	Eagle Creek, Leavanworth	2	WA	31.3	29.3	27.6	29.5	24	28.7	29.3
12008	Jack Creek, Cle Elum	2	WA	30.5	30.3	23.8	29.6	26.3	26.9	29.5
12009	Cougar Flats, Cliffdell	2	WA	29.5	26.5	25.1	27.6	28.6	29.3	29.3
12011	Clear Lake, Tieton River	2	WA	29.8	29	26	29.3	26.2	26.3	29.1
12012	Cascade Creek, Trout Lake	2	WA	31.8	27.2	25.5	28.1	25.1	28.6	29.1
12013	Cooper Spur, Parkdale	2	WA	27	27.2	21.9	25.3	26.1	26	28.7
12022	Boulder Creek	3/5	ID	*	*	25.2	27	*	*	28.3
12024	Usk	3/5	WA	*	*	23.7	28.1	24.7	*	29.4
12016	Santium Summit (31km NW Sisters)	4	OR	28	25.1	23.4	27.2	24.4	24.6	27.5
12018	Big Spring, Bend	4	OR	24	26.3	20.4	25.6	21.8	24.7	27.3
12020	Crescent Creek, Crescent	4	OR	27	27.1	22.4	26.4	24.6	26	27.9
12034	Dump Creek	3/5	ID	*	*	20.3	26.6	25.1	*	29.8
12015	Sisi Butte, Clackmas River	6	OR	31.2	29.9	24.4	29.2	24.2	28.6	29.9
12017	Tombstone Prairie	6	OR	27.5	28.7	21.6	27.4	22.2	25.4	26.6
12019	Roaring River Edge, Box Canyon	6	OR	26.7	25.3	22.3	27.2	24.3	24.4	28.6
12021	Whiskey Creek, Prospect	6	OR	29.2	24.1	24.7	25.6	*	21.4	27.3
12040	Salmon River, Sayward	7	VI	*	27.1	27.1	32.5	28.4	30.5	33.9
12042	Buckley Bay (25km S Courtenay)	7	VI	*	28.9	26.8	30.8	27.1	29	31
12043	Sproat Lake (15km W Port Alberni)	7	VI	*	29.5	27.3	33.6	27.9	29.1	31.9
12045	Yellow Point (40km SE Nanaimo)	7	VI	*	30.7	26.4	31.3	27.6	28.6	32
12047	Sooke (4km W)	7	VI	*	32.3	27.2	29.7	27.9	29.3	33.1
74(2002)	Craigvinean (37/48) (Commercial)	7	VI	31.5	30.4	25.4	32.9	29	30.7	30.6
12052	Pittsburg (12km N Vernonia)	8	OR	*	32.6	27.6	29.8	27.9	30.7	32.3
12053	Armstrong Road, Bluell	8	OR	*	26.8	26.3	29	25.5	28.8	31.8
12056	Norway (10km SE Coquille)	9	OR	*	30.2	25.1	30.1	29.3	30.7	32.3
12057	Otter Point (8km N Gold Beach)	9	OR	*	30.7	24.8	24.1	26.8	27.7	32
12036	Hagsholm Forest	10	DK	*	*	25.9	29.6	27.4	*	30.1

* Missing plots

** GYC based on Matthews *et al.* (2013)

For latitude, longitude and altitude of seed origins, see Fletcher and Samuel (1990)

Colour codes for GYC	
Dark green	28-30
Green	24-26
Yellow	20-22
Red	14-18

Table 2: Summary of experimental sites **(from ESC version 4* and experimental files)**

Site	Lat. (°N)	Long. (°W)	NGR	P. Year	DAMS	AT5	SMR	SNR	Soil	Suitability	Ann. rainfall (mm)
Alice Holt	51.20	0.87	SU787422	1979	11	1756	4 (moist)	5 (v. rich)	SW gley	0.65 Suitable	760
Brendon	51.13	3.42	ST004376	1979	13	1545	5 (fresh)	4 (rich)	Brown earth	0.78 V. suit	1200
Inchnacardoch	57.12	4.73	NH347070	1979	12	1203	5 (fresh)	1 (v. poor)	Podzol	0.66 Suitable*	1270
Mathrafal	52.68	3.23	SJ172093	1979	11	1470	5 (fresh)	3 (medium)	Brown earth	0.88 V. suit	1000
Speymouth	57.62	3.07	NJ362594	1980	12	1180	2 (wet)	1.5 (v. poor)	SW gley	0.6 Suitable*	750
Thetford	52.42	0.68	TL820840	1979	11	1776	7 (mod. dry)	4 (rich)	Brown earth	0.65 Suitable*	650
York	53.91	0.99	SE661467	1979	12	1665	3 (v. moist)	2 (Poor)	Brown earth	0.6 Suitable	550

* ESC v4 returned values of 0 for these sites and Stephen Bathgate carried out a more localised appraisal. The 0 values were returned due to soil mapping problems and/or the fact that for GF (and other species) if a site value is outside the tolerance range then suitability declines rapidly.

Table 3: Survival (%; year 10) of seed origins by region and site

Region	Alice Holt	Brendon	Inchnac.	Mathrafal	Speymouth	Thetford	York	Mean
1	91.5	85.5	61.7	89.7	84.2	87.0	94.0	86.9
2	88.6	86.5	52.4	91.8	88.8	94.5	94.5	88.4
3/5	-	-	58.3	90.2	94.7	-	99.1	85.6
4	75.6	72.4	43.6	86.7	87.6	93.8	85.8	81.2
6	82.0	78.4	50.7	91.0	94.2	71.7	98.3	87.7
7	92.0	82.2	69.1	86.2	76.9	85.6	93.8	85.2
8	-	73.3	64.7	91.3	86.7	85.3	96.0	82.9
9	-	76.7	46.7	80.0	76.7	88.0	80.7	74.8
10	-	-	70.7	97.3	93.3	-	97.3	89.7
Mean	85.9	79.3	60.0	90.4	88.8	86.6	95.6	

GLMM analysis showed that site ($p<0.001$) and region ($p=0.029$) were both significant as well as the interaction ($p<0.001$). Means are modelled values whereas site x region data (shaded) are actual means. Cells are shaded green/orange/red to show high/moderate/low values, this does not imply significance of pairwise comparisons.

Table 4: Mean height (cm; year 10) of seed origins by region and site

Region	Alice Holt	Brendon	Inchnac.	Mathrafal	Speymouth	Thetford	York	Mean
1	521	554	301	469	308	336	569	430
2	438	463	231	373	239	269	465	346
3/5	417	447	225	373	262	255	463	340
4	348	403	236	325	237	244	413	304
6	362	419	226	357	227	228	471	320
7	449	484	299	388	296	288	518	381
8	396	446	230	357	250	262	484	343
9	500	566	289	405	327	296	425	393
10	503	543	304	471	279	343	607	429
Mean	464	481	260	391	269	280	490	

REML analysis showed that site ($p<0.001$) and region ($p<0.001$) were both significant as well as the interaction ($p<0.001$). Means are modelled values whereas site x region data (shaded) are actual means. Cells are shaded green/orange/red to show high/moderate/low values, this does not imply significance of pairwise comparisons.

Table 5: Top height (m; year 40) of seed origins by region and site

Region	Alice Holt	Brendon	Inchnac.	Mathrafal	Speymouth	Thetford	York	Mean
1	31.7	31.8	26.6	31.0	28.2	30.2	31.2	30.1
2	30.4	28.3	24.6	27.9	26.2	27.8	29.2	27.7
3/5	-	-	22.3	27.1	24.8	-	29.1	25.8
4	26.3	26.2	22.1	26.4	23.6	25.1	27.5	25.3
6	28.6	27.5	23.3	27.2	23.5	25.7	28.1	26.2
7	31.4	29.8	26.7	31.9	28.0	29.5	32.1	29.9
8	-	29.7	27.0	29.6	26.7	29.8	32.1	29.1
9	-	30.5	25.0	26.4	28.0	29.2	32.2	28.5
10	-	-	25.9	29.5	27.4	-	30.1	28.2
Mean	29.7	29.1	22.3	25.7	23.6	24.6	27.2	

REML analysis showed that site ($p<0.001$) and region ($p<0.001$) were both significant but not the interaction ($p=0.192$). Means are modelled values whereas site x region data (shaded) are actual means. Cells are shaded green/orange/red to show high/moderate/low values, this does not imply significance of pairwise comparisons.

Table 6: Mean form score (year 40) of seed origins by region and site

Region	Alice Holt	Brendon	Inchnac.	Mathrafal	Speymouth	Thetford	York	Mean
1	2.4	1.9	2.5	1.9	2.7	2.0	2.0	2.2
2	2.2	1.9	2.4	1.6	2.8	2.0	1.9	2.1
3/5	-	-	2.4	1.7	2.8	-	2.1	2.3
4	1.6	1.1	1.9	0.9	2.7	1.7	2.0	1.7
6	2.0	1.7	2.2	1.5	2.7	1.6	1.8	1.9
7	2.2	1.6	2.7	1.7	2.5	1.8	2.1	2.1
8	-	1.5	2.5	1.2	2.6	1.4	2.1	1.9
9	-	1.7	2.4	0.5	2.5	1.8	1.9	1.8
10	-	-	2.7	1.8	2.8	-	2.1	2.3
Mean	2.1	1.6	2.4	1.4	2.7	1.8	2.0	

REML analysis showed that site ($p<0.001$) and region ($p=0.002$) were both significant as well as the interaction ($p<0.001$). Means are modelled values whereas site x region data (shaded) are actual means. Cells are shaded green/orange/red to show high/moderate/low values, this does not imply significance of pairwise comparisons.

4.0 References and acknowledgements

4.1 References

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4.2 Acknowledgements

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Appendix 1: FC Research Information Note 280

Forestry Commission **Research Information Note 280**

Issued by the Research Division of the Forestry Commission

THE INFLUENCE OF SEED ORIGIN ON THE GROWTH OF GRAND FIR IN BRITAIN,
by C.J.A. Samuel

Summary

This Note examines the growth of different seedlots of grand fir (*Abies grandis* Lindl.) drawn from 36 locations representative of most of its natural range. Performance was judged by comparing top height and diameter at breast height 15 years after planting at up to 10 evaluation sites in Britain. Those seed origins yielding the most suitable material for use across a range of sites are identified and the implications of these results in relation to the use of this species in Britain are discussed.

Introduction

1. *Abies* species have not been widely planted in Britain and account for less than 1% of the forest area. Since its introduction in 1830, *Abies grandis* has proved to be the most successful of the genus but, although it could achieve very fast rates of growth on good sites, the timber produced was of inferior quality (Aldhous and Low, 1974). Advantage was taken of the range-wide collection of seedlots made by the International Union of Forest Research Organizations (IUFRO) in 1976 and 1978 (Fletcher and Barner, 1978) to establish a definitive set of evaluation trials across a range of British sites. This Note examines recent data on diameter and top height measured 15 years after planting.

Evaluation trials: origins of seed; test sites and assessments

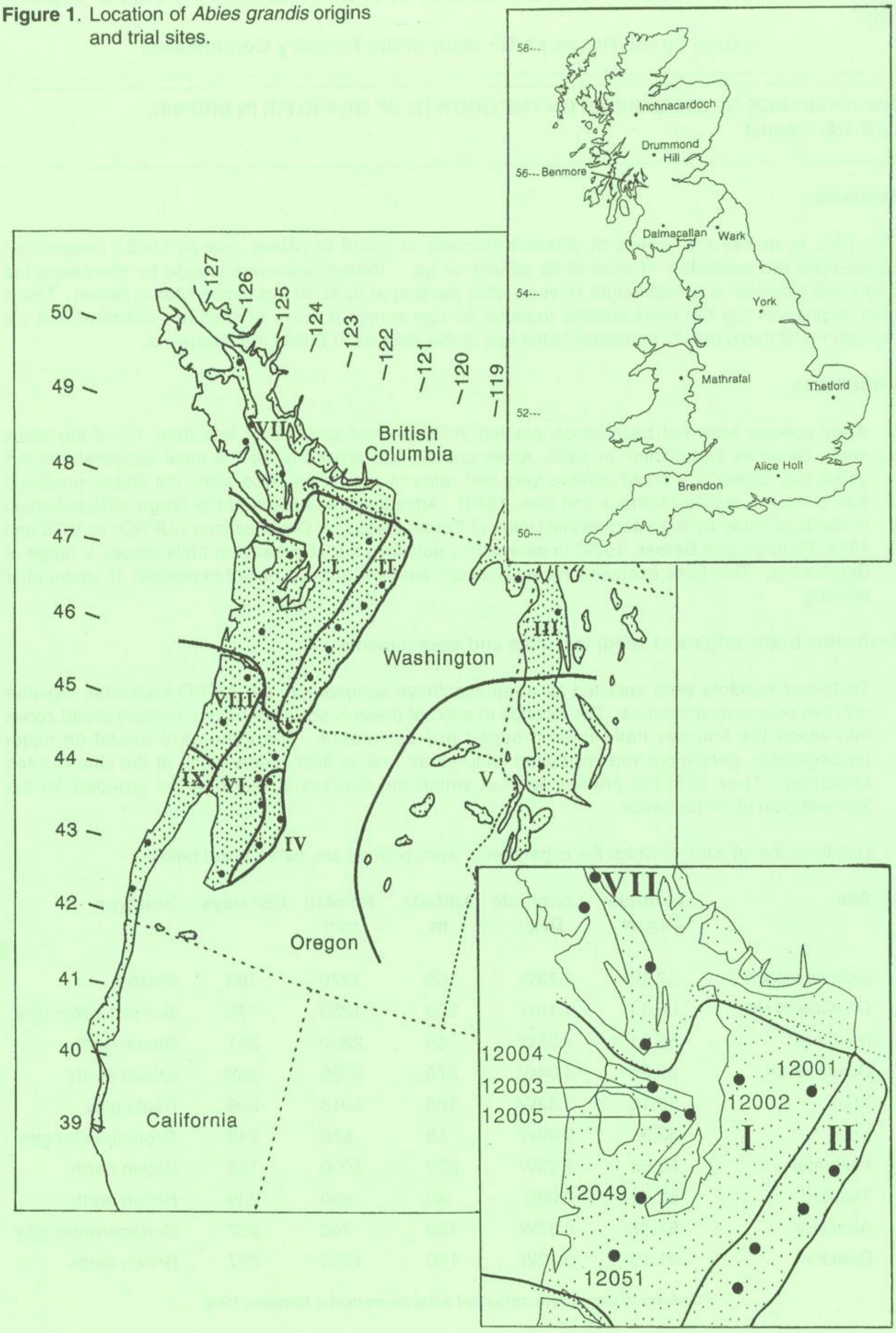
2. Thirty-four seedlots were selected as a representative sample from the IUFRO collection, together with two commercial sources. The location of each of these is shown in Figure 1 where broad zones into which the sources have been grouped are delineated. The zones are based on major physiographic, geological and vegetation features as well as field observations at the time of seed collection. They form the primary level at which the sources in test may be grouped for the interpretation of performance.

Details of the 10 sites at which the experiments were planted are summarised below.

Site	Latitude Deg. N	Longitude Deg.	Altitude m	Rainfall mm	GS* days	Soil type
Inchnacardoch	57.12	4.73W	105	1270	193	Podzol
Drummond Hill	56.54	4.10W	200	1250	176	Surface-water gley
Benmore	56.01	4.95W	150	2250	211	Brown earth
Dalmacallan	55.25	4.04W	270	2030	168	Brown earth
Wark	55.10	2.32W	168	1016	209	Peaty gley
York	53.91	0.99W	15	550	248	Ground-water gley
Mathrafal	52.68	3.23W	220	1000	188	Brown earth
Thetford	52.42	0.68E	40	650	239	Brown earth
Alice Holt	51.17	0.87W	120	760	237	Surface-water gley
Brendon	51.13	3.42W	150	1200	227	Brown earth

*Growing season in days, calculated using the method of Fairbairn, 1968

Figure 1. Location of *Abies grandis* origins and trial sites.



The location of the sites on a map of Great Britain is inset into Figure 1.

3. All experiments were established in 1979 using three replications of 25-plant square plots. Such a design is commonly used to yield useful information on growth for up to half the rotation age under British conditions. At the end of the 1993 growing season, the 15th after planting, the diameter of all trees was measured at breast height together with the height of the two trees in each plot which had the largest diameters (top height).

General performance of the seed sources across the natural range

4. Zone means at each site and across all sites are presented for both diameter and top height in Tables 1a and 1b respectively in which the first four letters of the site name are used to distinguish the test sites. For ease of presentation, both measurements have been expressed as a percentage of the mean of all sources at each planting site; the overall mean diameter and top height in original units is shown for the individual sites in the last line of each table.

Table 1a. Diameter 15 years after planting *(expressed as a % of mean diameter at each site)*

Origin	Inch	Drum	Benm	Dalm	Wark	York	Math	Thet	Alic	Bren	Mean
Zone I	111	109	115	111	106	107	113	117	111	107	110
Zone II	95	95	94	100	96	100	99	99	100	98	98
Zone III	84	94	87	92	89	99	89				95
Zone IV	88	85	86	79	89	88	87	88	86	89	86
Zone V	95	91	74	87	92	96	91				91
Zone VI	96	94	95	90	71	104	97	88	91	96	95
Zone VII	104	104	95	97	106	94	92	96	96	98	98
Zone VIII	88	97	98	107	101	95	93	92	100	97	97
Zone IX	96	111	105	110	91	87	100	92	106	109	101
Site mean (cm)	8.6	14.8	9.5	11.9	12.1	12.3	13.0	7.5	12.2	13.2	11.6

Table 1b. Top height 15 years after planting *(height (as % of site mean) of two trees with greatest diameters per plot)*

Origin	Inch	Benm	Dalm	York	Math	Thet	Alic	Mean
Zone I	113	112	110	104	105	114	109	109
Zone II	96	91	98	98	102	94	98	97
Zone III	80	90	99	99	105			97
Zone IV	77	83	86	95	90	86	86	87
Zone V	88	95	91	98	104			96
Zone VI	87	93	88	98	93	88	89	92
Zone VII	109	107	100	99	96	98	102	101
Zone VIII	101	95	100	98	98	97	97	98
Zone IX	101	107	107	96	88	106	107	101
Site mean (m)	8.2	7.5	8.2	9.4	10.3	6.7	10.9	8.7

5. From Table 1a it is clear that trees from the northern coastal Washington origins from Zone I have the largest diameters. Above-average performance is otherwise only shown in the southern coastal Zone IX. These two zone means contrast with the remainder which are consistently below average. Sources in Zones II and III are from east of the ridge of the Cascade Range in Washington. They appear to outperform more southerly counterparts from Oregon (Zones IV and VI) together with those from Zone V which extends to the most south-eastern part of the range where there is introgression with *Abies concolor* Hildebr.

6. Similar trends are to be found in the data for top height, available from only seven sites (Table 1b). Trees from sources of coastal origin are taller, with those from Zone I being the tallest followed by Zones VII and IX. The same superiority of the northern inland sources from Zones II and III over the southerly ones from Zones IV, V and VI is also evident.

7. The delineation of the natural range of grand fir into the zones considered in this evaluation, which was carried out before the experiments were planted, appears to form an acceptable basis for establishing those areas which may yield the most suitable seed for use under British conditions. The zones can be classified into three distinct groups; Zones I, VII and IX are of the truly coastal type and Zone VIII could be considered with these. Material from Zones II and III is of the interior type while that from Zones IV, V and VI is an interior type from the more southerly area of introgression with *Abies concolor*. There are large differences in rate of growth between the coastal and interior types.

Performance of individual sources within the most important zones for Great Britain

8. Zone I has produced the best overall performance as regards growth rate and this corresponds to the 'J-shaped area' recommended for the selection of Douglas fir seed sources (Lines and Samuel, 1987). This is not surprising since grand fir in the coastal areas of Washington and Oregon grows in mixture with Douglas fir in many places, although it has a preference for slightly richer soils. Trees from the seed sources within Zone I have consistently outperformed those derived from other regions; it is therefore relevant to examine in more detail the performance of individual sources in this zone. Diameter data (adjusted to percentages as in Table 1) are given in Table 2 for each of the eight sources sampled in Zone I; more exact details of the location of the sources are inset into Figure 1.

Table 2. Diameter for the individual sources in Zone I 15 years after planting *(expressed as % of mean diameter at each site)*

Origin	Inch	Drum	Benm	Dalm	Wark	York	Math	Thet	Alic	Bren	Mean
12001 Darrington	109	103	112	107	100	102	110	110	108	102	105
12002 Tulalip	99	107	117	109	114	110	116	118	107	106	110
12003 Elwha	113	108	134	111	111	115	122	117	111	117	115
12004 Sequim	112	114	113	108	96	100	111	117	104	99	106
12005 Louella	127	118	143	121	113	118	121	131	121	116	121
12049 Shelton	96	100	93	108	103	97	102	104	112	98	101
12051 Pe Ell	116	113	106	120	112	105	99	121	111	112	111
74(7973)5 Louella(C)	118	108	102	103	101	113	123				112

It is clear from Table 2 that most of the sources within this zone retain the clear superiority of performance already attributed to the zone mean, but the variation between some specific sources can be considered in more detail. The comparatively poor performance of Shelton (12049) may be based on the material having been collected in a small, remnant and possibly inbred population from the rain-shadow area in the Puget Trough where the soils are very poor glacial deposits. The most outstanding source is 12005, Louella, which has consistently outperformed all the others. This source is from the upper elevational limit of grand fir in the coastal areas of Washington and British Columbia. The commercial seedlot 74(7973)5, which was collected from a wide elevational band in the surrounding area and could be considered as the low elevation version of the Louella material, has not performed so well.

Comparative performance of second-generation material

9. Two further sources of seed were included in this series of tests, each derived from first generation planted material of European provenance. One source, 74(2002), was collected in a registered seed stand in Craigvinean Forest in the Tayside Region of Scotland in parent material which came from coastal British Columbia (Zone VII). In the second source, the parental material from which the provenance 12036 from Denmark derives is thought to have come from coastal Washington in Zone I. A comparison of each source with appropriate zone means for the IUFRO material given in Table 3 indicates that at all evaluation sites the Craigvinean provenance is superior to the parental zone mean, often by a substantial difference.

Table 3. **Comparison of second generation provenances with zone means for their respective parental origins *(diameter as % of site mean at 15 years)***

Origin	Inch	Drum	Benm	Dalm	Wark	York	Math	Thet	Alic	Bren	Mean
74(2002) Craigvinean	116	109	123	115	114	115	118	115	111	105	113
Zone VII mean	104	104	95	97	106	94	92	96	96	98	98
12036 Hagsholm, Denmark	113	109	128	109	115	118	116				117
Zone I mean	111	109	115	111	106	107	113				110

10. The difference is not so predictable or outstanding for the Danish material but a clear superiority overall is evident. Although details of the management of the Danish parent stand are not known, in the Craigvinean seed stand, the selection pressure in favour of a final crop of the most superior individuals has been so high that this stand ranks among the fastest-growing in Britain. These results indicate that selection of the better trees as parents among original material can have a beneficial effect on the performance of the next generation and supports the active registration of superior British stands of appropriate origins for seed production.

Conclusion and recommendations

11. Grand fir is not seen as having a major role as a timber species in Britain as the strength properties of the timber compare unfavourably with Sitka spruce and the species is prone to drought cracking. However it has the advantage of resistance to attack by the decay fungus *Heterobasidion annosum*. Growth rates can be very high giving maximum mean annual increments of more than 20 m^3 per hectare per annum and it has been proposed as an alternative to Sitka spruce.

12. Prior to the establishment of this series of experiments, grand fir was thought to be very specific in the types of sites on which it would perform well in Britain. To date the results show that acceptable rates of growth can be obtained up to the age of 15 years on a wide range of sites.

13. Seed sources from Zone I in Washington should be the primary choice for grand fir for general use in Britain. Among these sources, 12005 from Louella has consistently outperformed all others at most sites and its performance is followed by 12003, Elwha. The other coastal zones in British Columbia and Oregon (VII and IX), whilst performing well, still show no advantage over Zone I material. Sources from the introgression areas (Zones IV and V) show a wide mixture of growth characteristics and selections within this material could be made specifically for the production of Christmas trees. These sources have many slower-growing individuals of very good form, needle colour and retention.

14. Although these results indicate that trees from seed sources from Zone I should perform well over a range of sites in Britain, it must be remembered that the timber from grand fir has a lower basic density than Sitka spruce (Aldhous and Low, 1974). Indirect measurements of density made at the Wark and Drummond Hill sites showed clear variation both between and within zones (Bennuah, 1992). Whilst an inverse relationship between wood density and diameter growth was evident, there were clear instances of individual sources from the more vigorous zones having higher density. In general, however, with the very high growth rates which can be achieved on the best sites, it may be that some of the slower-growing sources from Zone VII or even Zone II and III should be used in order to obtain timber of better quality.

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