Forest Research

Summary of FR Seed Origin Trials on Noble fir (*Abies procera* Rehd.)

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The Research Agency of the Forestry Commission

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Front cover pictures: (left) Noble fir at Diana's grove, Blair Castle, Perthshire (1023055); (right) 30 year-old Noble fir of a similar size to the experiments in this study (1019265).

Contents

Executive summary

In a recent review of species research, noble fir (*Abies procera* Rehd.) was classed as a secondary species, i.e. in the past it has been planted on small scale but has potential for wider use in future (Kerr and Jinks, 2016). To ensure the potential of the species is realised there needs to be a scientific basis for future choices of seed origin. However, present guidance on the FR species and provenance webpage is slightly different to that in Forestry Commission Bulletin 66 (Lines, 1987). Both pieces of guidance are based on a series of 8 experiments examining 27 seed origins of noble fir established in the early 1980s.

In this project five of the original experiments were assessed and a new analysis undertaken to define the best geographical region for future seed collections. In addition, the literature was reviewed as a basis for making suggestions on future work to support the wider use of noble fir in British forestry.

The main findings were:

1. Noble fir is a productive forest tree and generally achieved GYC 16-20+ on the five sites studied. The best growth was achieved in the Forest of Dean and at Wykeham suggesting the possibility of a wider silvicultural niche for noble fir. At present noble fir is regarded to be most suited to upland Britain including higher elevations.

2. The results of this study suggest that the best areas for future seed collections of noble fir are the Cascade mountains in northern Oregon and southern Washington.

3. Further work on the limiting factors on the growth of noble fir is required so that the Ecological Site Classification Decision Support System produces better indications of suitability and reliable indications of yield.

4. One factor that could be important in the future for all *Abies* species in Britain is the canker *Neonectria* and further work on this should be a priority.

5. More work is also required to confirm the timber properties of noble fir grown in Britain. Existing published work by Ramsay and Macdonald (2013) and Gil-Moreno *et al*. (2016) is useful but constrained by small samples sizes from relatively young trees.

6. Further work is required to examine the survival and growth of provenances from Britain and how these compare with material from the native range.

1.0 Introduction

1.1. Context and history

The interest and use of noble fir in UK Forestry has increased in recent years due to the increased incidence of pests and diseases and the need to future-proof forestry in a changing climate. This includes the use of a wider range of species, mixtures and alternative silvicultural practices such as Continuous Cover Forestry (CCF) and Low Impact Silvicultural Systems (LISS).

Noble fir was first planted in the UK in the 1830s but did not attract much attention until the mid-1950s (MacDonald *et al*., 1957), after which there was increased planting especially on the Forestry Commission estate. The positive characteristics of noble fir include a high tolerance of exposure, being less moisture demanding than Sitka spruce, and less frost tender than other silver firs (Savill 2013). It also shows a relatively low incidence of pests and diseases although the recent discovery of *Neonectria neomacrospora* on silver firs in Wales is a concern (McMinn and Pérez Sierra, 2018). Historically the traditional niche for noble fir in British forestry has been on higher altitude sites, sites in which Sitka spruce would not grow and other species would be unproductive.

Not all authorities have viewed the species positively; for example, Aldhous and Low (1974) dismissed it in a single sentence: 'There appears to be no case for any large-scale planting of this species, because of its slow early growth and low density timber'. Slow early growth is a species characteristic of most *Abies* species in Britain and although this can be a problem for establishment, recent studies have shown that *Abies alba* and *A. amabilis* can be very productive in Britain (Kerr *et al*., 2015; Kerr *et al*., 2016). The point about low density timber is based on very little data and more recent work by Ramsay and McDonald (2013) shows noble fir to have a specific gravity of 0.39 compared with 0.34 for Sitka spruce. In a more recent review Mason (2013) suggested that previous reviews of the potential role of *Abies* species have been unduly pessimistic and that there should be an expanded place for silver fir species in the future of British forestry.

This study was commissioned by Stephen Smith, Forest Enterprise England to achieve the objectives set out in section 1.6 below.

1.2. Silviculture of noble fir

There is not a lot of published work on noble fir from the UK but there are a number of good references to its silvicultural characteristics in the north American literature. This indicates that noble fir is a pioneer species and is classed as 'intermediate' in terms of shade tolerance, being the least shade tolerant of all *Abies* species in the Pacific

Northwest. In natural mixed stands the species is eventually replaced by the more shade tolerant species such as Pacific silver fir and western hemlock (Franklin, 1983).

Noble fir's natural distribution is the Pacific Northwest of the USA, occurring mainly on the Cascade mountains from northern California to Washington (Figure 1). In its natural range, early growth is slow, taking up to 5 to 12 years to reach 1.3 m tall (Franklin, 1990) but growth from sapling to maturity is rapid. The species often establishes with Douglas-fir, in even-aged stands, after disturbances (mainly from fire) that create major stand openings (Franklin, 1983; Franklin *et al*., 1978; Stewart, 1986).

It occurs on steep slopes in the United States but grows best on gentle slopes, warm southern aspects with shallow to deep loams (Hemstrom *et al*., 1982; Franklin, 1990). In the Pacific Northwest it is commonly found at altitudes from 900m – 1600m although it can occur outside this range.

It is a moderately wind-firm species due its deep rooting potential on suitable soils and also has high frost tolerance (Arno and Hammerly 1977; Franklin 1983). It is therefore able to tolerate dry, exposed sites (not suitable for planting Sitka spruce), and is more exposure tolerant than Douglas-fir or grand fir (Savill, 2013).

In terms of planting, noble fir root systems are very sensitive to dessication and frost (McKay *et al*., 1997) therefore care needs to be taken in terms of storage and handling of trees prior and during planting. It also has low Root Growth Potential (RGP) (McKay *et al*., 1997), combined with slow early growth require the planting of noble fir on weed-free sites for successful establishment. It is has also been observed to be very susceptible to heather-check (Lines, 1987).

1.3. Pests and pathogens

Noble fir generally does not suffer major losses from pests or pathogens and is relatively resistant to *Heterobasidion annosum* (Savill 2013) and *Armillaria* spp. (Greig *et al*., 1991) but it is reported to be susceptible to the root and butt rot pathogen *Phaeolus schweinitzii* (Forest Research, 2017). There have been reports that it has suffered with branch dieback caused by *Phytophthora ramorum* (FERA 2015) but at the time of writing the main risk appears to be the species susceptibility to the emerging pathogen *Neonectria neomacrospora*, which causes dieback, cankers and in certain cases mortality (Forest Research 2016; McMinn and Pérez Sierra, 2018).

1.4. Genetics of noble fir

It is likely that the genetic variation of noble fir is less than other firs due to its comparatively restricted range. Noble fir hybridises readily with California red fir (*Abies magnifica*) to the south of its range (identified in this study as Region 1 in Figure 1) in a zone of introgression in southern Oregon and northern California (Franklin *et al*., 1978).

In its natural environment seed quality is often poor (10% viable seed) (Franklin 1990), and low germination percentages (35%) have been recorded in the UK (Gordon 1992).

In sapling trials in the USA, the amount of genetic and phenotypic variation in noble fir indicate moderate gains of stem growth can result from breeding and selection, with lesser gains available for stem form/branching (Doede and Adams 1998). Other studies have shown that northern provenances (45°N and above) tend to be superior in the maritime climate of British Columbia, Canada (Xie and Ying 1994), which may directly relate to the oceanic climate of the UK.

The Forestry Commission established a number of seed origin experiments on a wide range of conifers in the last century and noble fir was included in this initiative. The early results of height at years 3 and 6 were reported by Fletcher and Samuel (1990) and results after 32-34 years are presented in this report. These are the only experiments on the seed origins of noble fir in Britain, although there are three experiments in Ireland examining 15 seed origins but no data from these has been published (COFORD, 2012).

1.5. Timber properties

In the USA, the timber of noble fir is valued over other true firs due to its greater strength and Franklin (1990) notes that 'loggers called it larch to avoid the prejudice against the wood of true fir (this also influenced the naming of Larch Mountain, Oregon)'. A review by Ramsay and Macdonald (2013) indicated that the specific gravity of noble fir timber was 0.39, which is greater than UK grown Sitka spruce (0.34). Earlier work in Britain by Aldhous and Low (1974) indicated that noble fir has a lower specific gravity (0.32), MoR and hardness than other investigated species. However, their data were only based on material from five trees of unknown genetic origin.

Recent timber quality research on noble fir, Norway spruce, western red cedar and western hemlock from various sites in the UK has provided some contemporary data (Gil-Moreno *et al*., 2016). High yields of C14 (100% of samples tested) and C16 timber (96%) were obtained from noble fir, which was noted as being considerably younger than the other species tested and the authors noted that the properties of noble fir would probably be better had it been possible to sample trees of a comparable age to the other species.

The above summary indicates that a modern understanding of the species needs further investigation and information to ensure a potentially valuable timber tree is utilised correctly and not based on previous misconceptions.

1.6. Objectives of study

In 1982 to 1984 a series of eight experiments were established to examine the effects of seed origin on growth and yield of noble fir in Britain; five of these experiments were revisited in 2016/7. The objectives of this study are:

1. To examine growth of noble fir on contrasting sites throughout Britain using seed origin experiments that were planted in the early 1980s.

2. To determine the best locations for future seed collections in the native range of noble fir.

3. To make suggestions for further work on noble fir and define any gaps in knowledge of our present understanding and published advice on the species.

2.0 Seed origin variation in noble fir

2.1 Experiments

Seed from 27 origins in California and Oregon was available to the Forestry Commission in the late 1970s, 19 were from an IUFRO collection along with 8 further small commercial collections (Table 1). The seed was sown in the FC nursery at Fleet, Dumfries in 1979 and 1980 but due to a combination of poor germination and slow initial growth, transplants for the field experiments only became available between 1982 and 1984. There were not enough plants for fully replicated experiments at each of the eight sites planted so compromises were made. The eight sites planted are shown in Figure 2. In this study only five of the initial sites were revisited and it was decided not to assess Shin (poor growth on peat soil), Solway (Dean was also on a brown earth) and Moffat (Speymouth was also on an ironpan soil). However, the sites assessed covered a wide range of site conditions and geographic range and are described in Table 2.

Each of the five experiments were randomised blocks and the standard plot size was 30 trees (6 x 5 planted at 2 m x 2 m) but there were a few differences at each site. The Dean experiment contained 24 provenances in 5 blocks; at Glasfynydd there were 16 provenances in 4 blocks; at Wark there were 16 provenances in 3 blocks and the plot size was 49 trees; at Wykeham there were 16 provenances in 4 blocks with an additional block of plots of 81 trees. At Speymouth one experiment was established with the planting material that became available in 1982 and another with the provenances available in 1983; each experiment had 4 blocks and an additional block of 49 trees. Good establishment practice was used at each of the sites and only a small amount of beating-up was carried out. At the time of the latest assessment the experiments were unthinned except Dean, which had been line thinned.

For each of the seed origins information was available from Fletcher and Samuel (1990) on latitude, longitude and altitude as well as the nearest place (Table 1).

2.2 Assessments and analyses

2.2.1 Assessments

Four of the sites were assessed between December 2016 and March 2017 and Glasfynydd was measured in June 2017. Each site was assessed using the same protocol:

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);

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 has been taken as an estimate of top height and from this an assessment of General Yield Class (GYC) was made using the top height-age curves for noble fir in Matthews and Mackie (2006). In addition, the volume of each plot was estimated by: (1) calculating plot basal area (number of trees x basal area of tree of mean DBH); (2) estimating form height using equation 6 in Matthews and Mackie (2006)(p.325); (3) multiplying plot basal area by form height; (4) adjusting plot areas to that of the 30 tree plots (x0.612 for 49 tree plots and x0.37 for 81 tree plots). At Wark five plots had been badly affected by windblow and only a proportion of trees in these plots had been safe to assess. For these plots we assumed the mean diameter of the assessed trees was applicable to all live trees (standing and windblown).

The analysis of the height of these experiments after three and six years by Fletcher and Samuels had used analysis of variance to answer the question: which seed origin is best? The most vigorous origin was shown to be collection 13008 from Laurel Mountain in the Coast Range (Region 4 on Figure 1). However, this result presents a dilemma for another, possibly more, relevant question of: in which area should seed collections be focussed considering growth conditions in Britain? The main reason for the dilemma is that the worst collection was the other collection from the Coast Range, 13004, Mary’s Peak. Hence in this study we have focussed on a more practical question: in which area should seed collections be focussed to obtain good growth in Britain? To group each of the seed origins into regions we have used the classification suggested in Fletcher and Samuel (1990), which is shown in Figure 1.

2.2.2 Effects of seed origin and site

Given the unbalanced distribution of material from the 27 seed origins across the sites, the response variables top height, mean DBH and volume were analysed by linear mixed models using the method of residual maximum likelihood (REML). The form scores were analysed by generalised linear mixed models (GLMM), fitting a multinomial error distribution and cumulative 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 five experiments (sites) each with between three and five blocks (blocks) and the 27 seed origins (seed origins) were treated as samples of the 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 (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 16 (Payne *et al*., 2009).

2.3 Results: seed origin and site

2.3.1 Top height

- Estimates of top height ranged between 11.7 m (Region 1; Glasfynydd) and 22.0 m (Region 2; Wykeham) after 33 years (Table 3).
- There were significant differences between sites, the best sites were Dean and Wykeham and the other three were much lower.
- There were also significant differences between the Seed Regions with the order being 2=3>4>1.
- The estimates of top heights were used to give an indication of GYC and these ranged between 10 and 22 (some were above the upper limit so could be GYC 24 or 26). The fact that Dean and Wykeham were more productive sites that the other three can clearly be seen in Table 1.
- The interaction of Site and Region was significant but generally Regions 2 and 3 were the top two height rankings at the 5 sites, so this is probably of little practical relevance.

2.3.2 Diameter

- Mean diameters ranged between 13.3 cm (Region 1; Speymouth-82) and 30.1 cm (Region 4; Dean) after 33 years (Table 4).

- There were significant differences between sites and the pattern between them was the same as for top height. The best sites were Dean and Wykeham and the other four were much lower.
- There were also significant differences between the Seed Regions with the order being 4>2=3>1.
- The interaction of Site and Region was significant but generally the highest ranks were from Regions 2, 3 and 4 across the five sites, so this probably has little practical relevance.

2.3.3 Volume

- Estimates of plot volume ranged between 0.8 m^3 (Region 1; Glasfynydd) and 7.0 m^3 (Region 2 and 4, Wykeham and Region 4, Dean) after 33 years (Table 5).
- There were significant differences between sites, the best sites were Dean, Wykeham and Wark and the other three sites were much lower.
- There were also significant differences between the Seed Regions with the order being 4=3>2>1.
- The interaction of Site and Region was not significant.

2.3.4 Form score

- Analysis showed no differences between form scores (Table 6) and all values were about 2, i.e. the trees had a single stem and leader but some kinks in main stem and/or heavy branching indicating they were potential timber trees.

2.5 Conclusions

1. Noble fir is a productive forest tree and achieved GYC20+ on a brown earth soil in the Forest of Dean and an ironpan at Wykeham. The three other sites had lower yield but even on these most seed origins were GYC16+ including a peaty gley soil at 440 m elevation at Glasfynydd. These results suggest that the silvicultural niche for noble fir could be significantly increased to include a much wider range of sites. At present the FR species and provenance website summarizes this as 'Prefers a cool and moist (i.e. >1000 mm rainfall) climate; can cope with exposure and is more frost resistant than other firs, therefore most suited to upland Britain including higher elevations' and ' It may have an increased role for diversifying spruce forests in western Britain.'
2. The results of this study suggest that Regions 2 and 3 (the Cascade mountains in northern Oregon and southern Washington) are the best areas for future seed collections for the use of noble fir in Britain. Region 4 (coastal Washington) showed good results but was based on only two samples and therefore more work

is required to confirm if this should be given equal status to Regions 2 and 3. This confirms present advice on the FR species and provenance webpages, which is that 'Provenances from the Washington or north Oregon Cascade mountains or from good quality British stands should be used'. However, that published by Lines (1987; reproduced below) is somewhat different and keener to identify good local areas for seed collections rather than broad regions.

3. Further work on the limiting factors on the growth of noble fir is required so that the Ecological Site classification Decision Support System produces better indications of suitability and reliable indications of yield. ESC version 4 indicates that noble fir is unsuitable for the Wykeham and Glasfynydd sites; which based on the results of this study is wrong.

4. To meet increased demand for see of noble fir in the future, these seed origin experiments could be used as seed stands and, if so, it may be best to remove the seed origins from Region 4. This should be accompanied by further work to examine survival and growth of provenances from Britain.

5. One factor that could be important in the future for all *Abies* species in Britain is the canker *Neonectria* (see https://gd.eppo.int/reporting/article-2696 and McMinn and Pérez Sierra, 2018).

6. In addition, more work to confirm the timber properties of noble fir is justified due to the small number of samples used in Ramsay and Macdonald (2013) and the younger age of the trees in (Gil-Moreno *et al*., 2016).

Extract from Lines (1987) on noble fir

'Recommendations

1. The scanty research evidence points mainly at areas to avoid, i.e. the introgression zone south of latitude 44°N and perhaps Mary's Peak, which lies on the border between seed zones 061 and 252. However, the Laurel Mountain, which is also in the Coast Range, Zone 251, grew well.

2. The most promising source appears to be Larch Mountain, Oregon at 975 m, which lies east of Portland in Zone 451. This is close to the area where David Douglas was prospecting in 1825.'

3.0 Tables and Figures

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

							Height (m)				
Seed origin	Location	Zone	Region	Lat.	Long.	Alt (m)	Dean	Glasfynydd	Wykeham	Wark	Speymouth
13001	Odell Butte (W/Crescent)	I	OR	43.45	121.87	1950	22.7	*	*	*	17.5
13002	Juniper Ridge (S/Oakridge)	I	OR	43.58	122.33	1700	*	*	*	*	14.0
78(7955)500	Surveyor Mountain	I	OR	42.25	122.25	1676	19.1	11.3	18.3	*	13.6
67(7955)500	Glide Ranger Dist. (E/Steamboat?	I	OR	43.33	122.50	1750	17.8	*	*	*	13.5
71(7952)500	Galice Ranger Dist. (Sugarloaf Mt?	I	OR	42.50	124.00	1300	18.3	12.1	*	*	14.4
13005	Fisher Pt., Scar Mt.Rd. (S/Idanha)	II	OR	44.55	122.03	1220	19.8	*	22.3	15.3	17.5
13007	Elk Lake (N/Detroit)	II	OR	44.82	122.10	1200	21.0	*	21.0	17.4	16.6
13009	One Hundred Road (E/Molalla)	II	OR	45.10	122.30	1130	19.2	16.0	22.7	14.4	17.9
13010	Elk Mountain (SE/Mt.Hood)	II	OR	45.33	121.65	1220	20.1	15.6	22.0	14.8	17.5
13011	Larch Mountain (E/Portland)	II	OR	45.53	122.10	975	19.4	16.8	21.8	16.2	16.6
13012	Mt. Defiance (NW/Dee)	II	OR	45.63	121.73	1125	20.0	*	21.8	16.4	16.5
68(7953)500	Clear Lake	II	OR	44.33	122.00	1300	21.1	*	*	*	16.3
68(7953)501	Clear Lake	II	OR	44.33	122.00	1450	19.8	*	*	*	15.3
13013	Larch Mountain (E/Battleground)	III	WA	45.72	122.28	975	20.0	17.2	20.9	14.2	15.4
13014	Red Mountain (W/Trout Lake)	III	WA	45.93	121.83	1220	19.9	17.5	20.9	11.4	17.3
13015	Hungry Peak (E/Swift Cr. Reservoi	III	WA	46.12	121.90	1280	*	*	*	18.3	17.3
13016	French Butte (S/Randle)	III	WA	46.33	121.95	1300	20.3	16.4	21.9	16.7	17.5
13017	Mud Lake (S/Packwood)	III	WA	46.40	121.62	1425	21.9	*	22.4	16.6	16.6
13018	McKinley Lake (E/Morton)	III	WA	46.58	122.13	900	20.1	15.5	22.2	18.0	17.5
13019	Corral Pass (NE Mt. Rainer)	III	WA	47.02	121.47	1615	*	*	*	*	18.3
13020	Stampede Pass (N.Cascades)	III	WA	47.23	121.37	1065	20.0	16.0	22.0	17.3	17.5
13021	Stevens Pass (N.Cascades)	III	WA	47.72	121.33	1000	18.7	16.7	21.6	17.1	16.6
78(7974)500	Sun Top Mountain (Seed stand)	III	WA	47.03	121.60	1140	19.9	16.5	21.8	*	16.8
78(7975)500	Coal Creek Mountain	III	WA	46.67	121.50	1450	20.6	16.1	21.7	*	17.6
78(7975)501	Clear Creek	III	WA	46.13	122.00	1140	21.1	17.2	20.8	*	16.6
13004	Mary's Peak (SW/Philomath)	IV	OR	44.50	123.55	1065	19.5	15.8	21.2	15.7	15.6
13008	Laurel Mountain (NW/Falls City)	IV	OR	44.93	123.58	975	20.1	14.8	22.0	18.0	17.6

	YC
	20+
	16-18
	10-14

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

Site	Lat. (°N)	Long. (°W)	P. Year	Alt (m)	DAMS	AT5	SMR	SNR	Suitability	Limiting factor
Dean	51.88	2.54	1983	145	11	1660	5 (fresh)	4 (rich)	0.62 Suitable	MD
Glasfynydd	51.89	3.66	1983	440	17	1128	2 (wet)	2 (poor)	0.0 Unsuitable	SMR
Wykeham	54.28	0.52	1984	198	14	1353	5 (fresh)	0.5 (v. poor)	0.1 Unsuitable	SNR
Wark	55.11	2.31	1982	168	14	1283	3 (v. moist)	3 (medium)	0.65 Suitable	SMR
Speymouth	57.57	3.11	1982	155	14	1083	3 (v. moist)	2 (poor)	0.65 Suitable	SMR

Table 3: Top height of the noble fir seed origins by Region and site

Region	Dean	Glasfyn.	Wykeham	Wark	Spey-82	Spey-83	Mean
1	19.0	11.7	18.3	*	14.6	13.9	15.3
2	19.8	16.1	22.0	15.7	17.1	15.8	17.9
3	20.1	16.5	21.6	16.2	17.1	16.8	18.1
4	19.8	15.3	21.6	16.5	16.6	*	17.6
Mean	19.6	15.3	20.9	15.3	16.3	15.8	
REML analysis showed that Site (P<0.001), Region (P<0.001) and their interaction (P=0.004) were all significant. Means are modelled values (Site SED = 0.72; Region SED =0.28) whereas site x region data (shaded) are actual means.							

Table 4: Mean diameter of the noble fir seed origins by Region and site

Region	Dean	Glasfyn.	Wykeham	Wark	Spey-82	Spey-83	Mean
1	23.5	13.4	19.8	*	13.3	14.5	16.8
2	29.8	17.5	25.6	18.7	16.1	15.9	20.7
3	28.6	17.2	25.5	19.8	16.9	16.9	20.9
4	30.1	18.2	26.2	20.4	16.6	*	21.6
Mean	28.3	16.5	24.7	18.5	15.7	16.5	
REML analysis showed that Site (P<0.001), Region (P<0.001) and their interaction (P=0.022) were all significant. Means are modelled values (Site SED = 0.98; Region SED =0.543) whereas site x region data (shaded) are actual means.							

Table 5: Plot volume of the noble fir seed origins by Region and site

Region	Dean	Glasfyn.	Wykeham	Wark	Spey-82	Spey-83	Mean
1	3.86	0.76	4.00	*	2.34	1.53	2.69
2	6.51	4.57	7.03	5.17	4.51	2.72	5.13
3	6.21	4.46	6.81	6.03	4.95	3.38	5.38
4	6.96	4.29	7.03	6.82	4.50	*	5.45
Mean	5.87	3.65	6.34	5.09	4.10	2.93	

REML analysis showed that Site (P<0.001) and Region (P<0.001) were significant but not their interaction (P=0.275). Means are modelled values (Site SED = 0.59; Region SED =0.38) whereas site x region data (shaded) are actual means.

Table 6: Mean form score of the noble fir seed origins by Region and site

Region	Dean	Glasfyn.	Wykeham	Wark	Spey-82	Spey-83	Mean
1	2.21	2.06	1.92	*	1.97	2.00	2.02
2	2.09	1.84	1.72	2.11	1.69	1.84	1.87
3	2.01	1.83	1.74	1.99	1.72	1.72	1.83
4	1.99	1.80	1.78	2.00	1.78	*	1.89
Mean	2.07	1.88	1.79	2.05	1.79	1.84	

GLMM showed that neither Site nor Region were significant. Means are modelled values whereas site x region data (shaded) are actual means.

Figure 1: The species range of Abies procera showing seed origins and the four seed regions used in this study (from Fletcher and Samuels (1990))

Figure 1. Location of IUFRO Noble fir seed origins

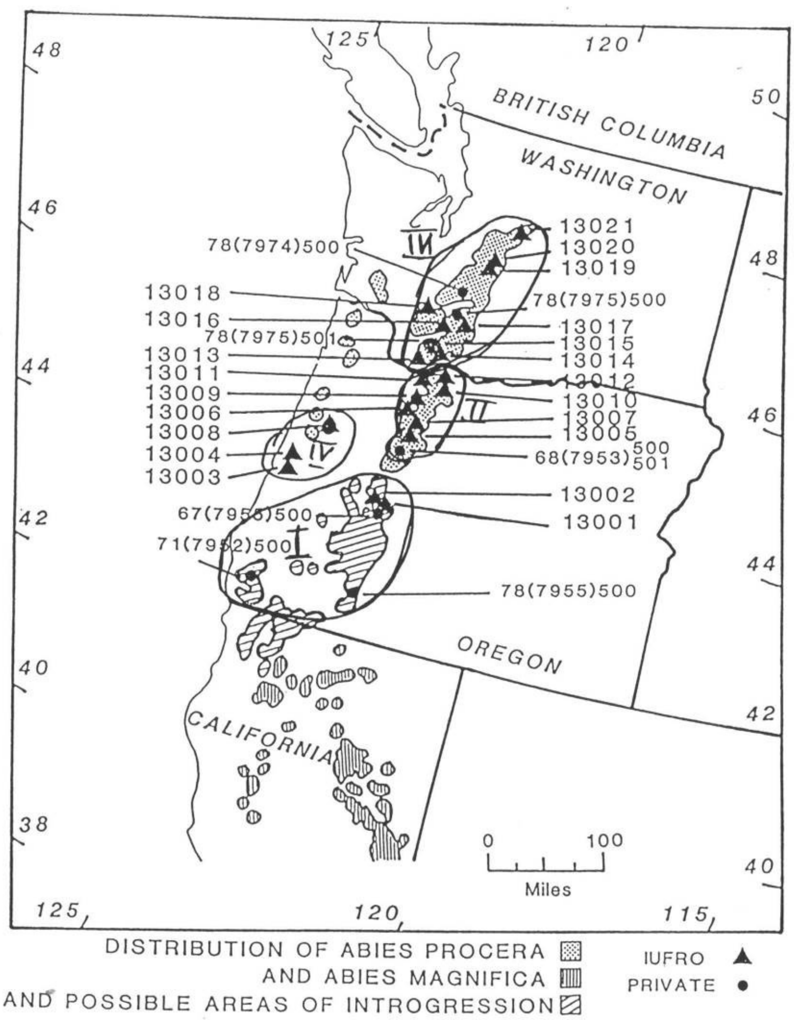
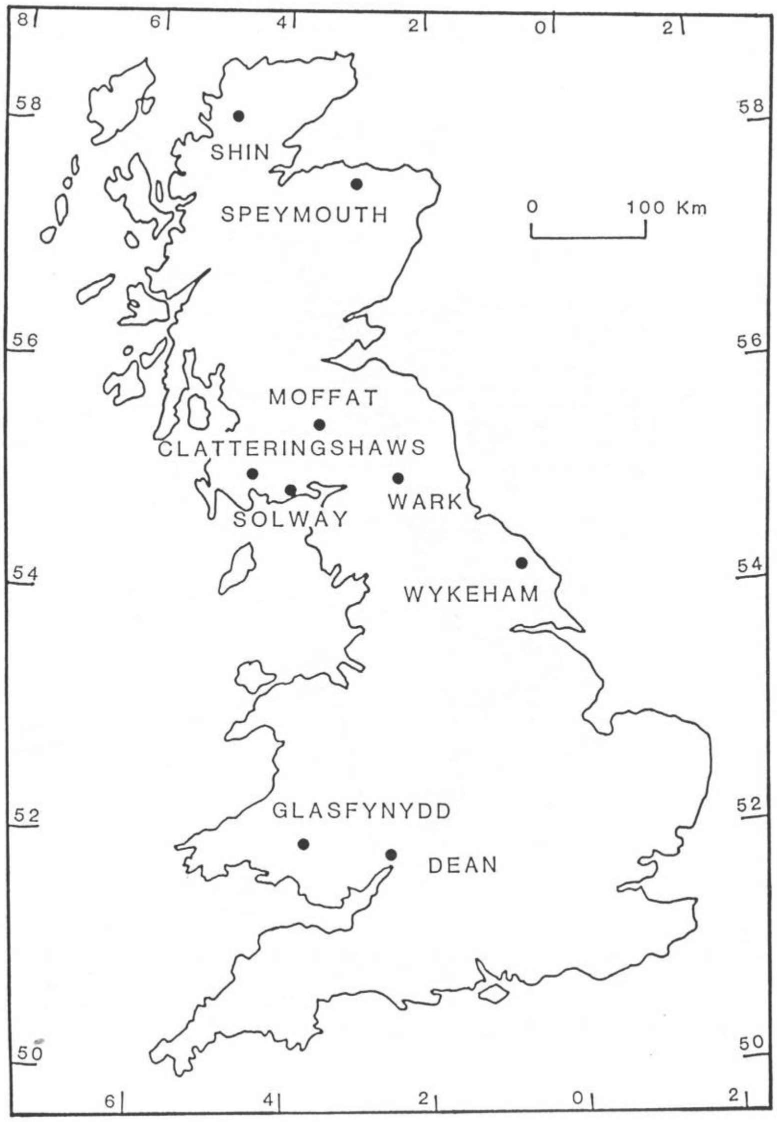


Figure 2: Map showing the locations of the experiments in Britain (5 were re-assessed for this study)

Figure 2. Location of IUFRO Noble fir seed origin experiments in Britain.



4.0 References and acknowledgements

4.1 References

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4.2 Acknowledgements

The authors are grateful to people who initially established the trials, members of Forest Research's Technical Services who reassessed the experiments and Jack Forster who advised on the analysis of the data.

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