Forest Research

Summary of FR Seed Origin Trials on western red cedar (*Thuja plicata* D. Don)

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Front cover pictures: (Left) Western red cedar in the experiment Thetford 84 planted in 1963. GYC of the seed origins was 16-20 on a podsol with 620 mm rainfall a year; note characteristic exaggerated taper and fluting on lower stem. (Right) Open grown specimens of western red cedar at Westonbirt arboretum.

Contents

Executive summary

In a recent review of research, western red cedar (*Thuja plicata* D. Don) was classed as a *secondary species*, i.e. in the past it has been planted on a small scale but has potential for wider use in future (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 and a better understanding of the limiting factors to its growth in Britain. Present guidance on seed origins is that western Washington or Vancouver Island should be preferred (Lines, 1987; Forest Research, 2019). However, it’s unclear how these recommendations were supported by analysis of the available data from six experiments examining 13 seed origins established in the early 1960s.

In this project three of the original experiments were reassessed and the most recent data available from the other closed experiments were analysed to define the best geographical region for future seed collections. In addition, the literature was reviewed, including a significant new analysis by Jinks (2017), as a basis for making suggestions on future work to support the wider use of western red cedar in British forestry.

The main findings were:

1. Western red cedar is a productive forest tree and generally achieved GYC 16-22 on the six sites studied. In Britain, soil type and exposure probably have a greater influence on growth compared with rainfall and temperature but our current understanding of these factors is inadequate. The potential of western red cedar is possibly greater than currently realised and certainly much wider than just the uplands. As a shade tolerant species that produces viable seed it has positive attributes for greater use in continuous cover management.
2. The results of this study confirm that the best areas for future seed collections of are in the coastal region of Washington and British Columbia between 46°N and 50°N. Further work is also required to examine the survival and growth of provenances from Britain and how these compare with material from the native range.
3. Further work on the limiting factors on the growth of western red cedar should be carried out to with the objective of enhancing the Ecological Site Classification Decision Support System ratings for suitability and improving the accuracy of indications of yield.
4. More work is also required to confirm the timber properties of western red cedar grown in Britain and should be focused on enhancing specific gravity and understanding the causes of enhanced taper and fluting of the lower stem.

1.0 Introduction

Western red cedar is currently considered a minor species and the latest figures show that it occupies 7179 ha of forest in Britain[1] (Gilbert, pers. comm.). Interest in western red cedar has risen in recent years due to the increased incidence of pests and diseases and the need to adapt forests for a changing climate. Western red cedar could be particularly useful in this regard as it has silvicultural characteristics that render it suitable for wider use in mixed-species stands and alternative silvicultural practices such as Continuous Cover Forestry (CCF) and Low Impact Silvicultural Systems (LISS).

In the following four sections the information presented for western red cedar on the Forest Research species and provenance webpages (Forest Research, 2019) is shown in italics (numbers, i.e. [1] have been added for ease of referencing). This guidance is then reviewed based on current knowledge and thinking as well as the information presented in Zehetmayr (1954), Wood (1955), MacDonald *et al.* (1957), Aldhous and Low (1974), Minore (1990), Lines (1987), Oliver *et al.* (1988), Pyatt *et al.* (2001) and Jinks (2017).

1.1 Silviculture

Site requirements

A shade tolerant species with good vigour and volume production, although early growth can be slow [1]. Best suited to more humid regions with an annual rainfall of > 800 mm [2]. Cold hardy throughout Britain, moderately frost tolerant, does not withstand exposure, but is moderately drought tolerant [3]. Vulnerable to fungal attack in nurseries which historically has restricted planting stock availability [4]. Grows best on medium to very rich soils with fresh to moist soil moisture but will tolerate calcareous soils if grown under light shelter [5]. Not suited to very poor and very dry soils but will grow on gleys and occurs on some peat soils in its natural range [6]. Can be grown in mixture with a range of conifer and broadleaved species [7].

Uses

Currently a minor species in Britain, but may find an expanded role as a means of diversifying upland conifer forests as an adaptation to projected climate change [8].

With reference to the above numbered sentences:

[1] There is good evidence for this statement.
[2] Recent work by Jinks (2017) showed that productivity was not greatly affected for the range of temperature and moisture on sites where it has been planted on the Public Forest Estate. The lower limit of 800 mm rainfall is probably based on the lower level of rainfall in its coastal range (Minore, 1990).

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[1] The figures are 5793 ha (±11%) for privately owned woodlands estimated from the National Forest Inventory and 1386 ha for the Public Forest Estate.

[3] This information is mainly based on observation of trees growing in even-aged stands. The real limits to growth in Britain are probably worthy of further examination including the effect of how these change with different silvicultural systems. The analysis of Jinks (2017) has shown potential for red cedar on colder, wet sites than where it has traditionally been planted (on warmer, humid sites).
[4] See section 1.2 below.
[5] The statement that red cedar will grow best on the better sites is no surprise but growth on carbonate sites is more likely to be more strongly related to depth of soil than the presence of shelter.
[6] As with [3] above; the growth of red cedar on peaty gleys and other organic soils is worthy of further examination. Work by Zehetmayr (1954) indicated potential but this has not been further investigated.
[7] The shade tolerance means that it is a good species for mixed-species stands and can be underplanted. When young the crown is quite narrow; in the experiment Benmore 8 (see below), ten year-old trees initially planted at 1.5 m x 1.5 m spacing and 2.7 m tall had not closed canopy.
[8] Arguably a conservative vision for its future potential.

1.2 Pests and pathogens

Pests and pathogens

Markedly susceptible to Armillaria (honey fungus) as a cause of decay and death, and to Heterobasidion (Fomes root and butt rot) as a cause of decay [8]. Cypress aphid (Cinara cupressivora) is a not uncommon cause of foliage browning on western red cedar [9].

There is good evidence to support these statements. However, comment [4] relates to Keithia blight (*Didymascella thujina*) a fungus that infects 2nd- and 3rd-year nursery seedlings and can cause up to 97% mortality (Boyd, 1965); fortunately the blight can now be successfully controlled (Burdekin and Phillips, 1971). The deployment of western red cedar may in the past have been 'nursery constrained' because of this fungus in the similar way that *Abies* species were also constrained by exaggerated concerns about *Adelges* (Kerr, 1999).

1.3 Genetics

Native range

Native to the Pacific north-west of America with a wide range from Alaska to California and also inland to the Cascade Mountains.

Provenance choice

Limited provenance testing suggests that seed sources from western Washington or Vancouver Island should be preferred.

The guidance on provenance is based on Lines (1987) although it's unclear what data analysis was carried out to support this conclusion. However, the findings are supported by information from the native range. Minore (1990) suggests that optimal growth and development are achieved near the latitudinal centre of its range on Washington's Olympic Peninsula. In addition, it is noted that 'western red cedar seems to vary less than other northwestern conifer species'.

1.4 Timber properties

Use

Currently a minor species in Britain, but may find an expanded role as a means of diversifying upland conifer forests as an adaptation to projected climate change.

Work by Aldhous and Low (1974) showed that the specific gravity of red cedar is 0.32, which is lower than UK grown Sitka spruce (0.34); Savill (2013) suggests a higher figure of 0.39. Some more recent work by Gil-Moreno *et al.* (2016) shows that red cedar can produce high yields of C14 (100% of samples tested) and C16 timber (94%). Minore (1990) comments that 'the wood is valuable and extensively used in a variety of products' in its native range and this is probably due to the durability of the heartwood.

A species characteristic that has not received much attention is the peculiar shape of the lower stem. This is caused by 'butt swell', where the lower part of the stem has much greater taper compared with the rest of the tree; and 'fluting', caused by prominent ridges that develop into roots below the soil surface. There is little information on these features in the literature; Oliver *et al.* (1988) discuss possible causes and propose solutions in the context of harvesting trees from old-growth mixed species stands in the Pacific Northwest. Their proposed solution to control these features is to grow red cedar in pure stands planted at relatively close spacing, which is similar to how the species has been deployed in Britain.

1.5 Objectives of study

In 1962/3 a series of seven experiments were established to examine the effects of seed origin on growth and yield of western red cedar in Britain; three of these experiments were revisited in 2017/18. The objectives of this study are:

1. To examine growth of western red cedar on contrasting sites throughout Britain using seed origin experiments that were planted in the early 1960s.

2. To determine the best locations for future seed collections in the native range of western red cedar.

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

2.0 Seed origin variation in red cedar

2.1 Experiments

Seed from 13 origins in British Columbia, Washington and Oregon was available to the Forestry Commission in the late 1950s and a decision was taken to establish seven seed origin experiments. Three of the experiments were located in southern England (New Forest 19, Alice Holt 127 and Thetford 84); one in Wales (Radnor 36), one in the Midlands (Cannock 9); one in northern England (Thornthwaite 3) and one in Scotland (Benmore 8). Seed for the five more southerly sites was sown in the FC nursery at Alice Holt in 1960 and this eventually yielded between 337 and 1098 useable 1+1 transplants for each seed origin. For the two northerly experiments, seed was sown at Tulliallan nursery, near Stirling (nursery experiment Tulliallan 2/60 HLN) and this yielded 400 useable 1+1 transplants of each seed origin. Such small numbers of trees compromised the scope of the experiments and a decision was taken to vary their design and size to accommodate this (Appendix 1). In the south, the main site in the New Forest was allocated 300 plants of each seed origin but the other five sites were each given between 26 and 72 plants. In the north, Benmore and Thornthwaite were allocated 144 and 256 trees of each seed origin respectively.

The experiment at Cannock unfortunately failed due to frost but it was the smallest trial with only 26 trees of each seed origin. There was also a problem at Thornthwaite and the experiment had to be replanted with 36 tree plots instead of the initial planting of 64 tree plots. In this study only three of the initial sites were located and judged to be 'assessable' (New Forest 19, Thetford 84, Radnor 36). The last assessment for the other three experiments was retrieved and made available for analysis; this was after 10, 16 and 17 years for Alice Holt, Thornthwaite and Benmore respectively. The availability of these historic assessments was valuable as it provided an opportunity to test the conclusions from the three existing sites in southern England and Wales against two more northerly sites.

The sites covered a wide geographical range and also had varying rainfall (620 – 2200 mm yr^{-1}), temperate (1242-1864 day degrees), soil nutrient regimes (poor to very rich) and exposure (DAMS 10-15); however, it is worth noting that all the experiments were planted on free-draining mineral soils (Table 2). It should also be noted that the four southern sites had some degree of shelter when established, in the form of an overstorey or coppice, whereas the northern experiments and Cannock were planted on restocking sites[2] (Table 2). 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 most recent assessment each of the three experiments had been thinned at least once.

[2] Lines and Aldhous (1964) describe the early establishment of these experiments. Cannock failed as it was planted in a frost hollow; Thornthwaite had to be replanted due to 'drought and other causes' and Benmore suffered in the severe winter and had considerable leader dieback.

For each of the seed origins information was available from the experiment plan on latitude, which was accurate, but data on altitude and 'distance from coast' was much more general (Table 1); no information was recorded for longitude. It should be noted that none of the seed origins was from the inland range of western red cedar in eastern British Columbia, Idaho and Montana (Figure 1).

2.2 Assessments and analyses

2.2.1 Assessments

The experiments New Forest 19, Thetford 84 and Radnor 36 were assessed between October 2017 and March 2018. 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; 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 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 western red cedar in Matthews and Mackie (2006). The mean height at Alice Holt 127, Thornthwaite 3 and Benmore 8 was also used to estimate GYC <u>for the site</u> using the same method.

2.2.2 Effects of seed origin and site

The analysis suggested in the experiment plan is quite different to that carried out at Benmore for the 17 year height data (Appendix 2). The analysis of the Benmore data, probably by Chris Samuels, used analysis of variance to answer the question: which State (or part of a State) was the best seed origin for planting? The results showed that Washington and Vancouver Island were the best. However, this analysis did not take into account the availability of data from the other experiments and it's not clear how this wider set of data were used to support the recommendations for seed origins in Lines (1987).

In this study data from all six sites has been analysed to answer the question: in which area should seed collections be focussed considering growth conditions in Britain? To group each of the seed origins into regions the latitudinal range was divided into three: Region 1 – above 51°N; Region 2 – above 47°N (but below Region 1); Region 3 – above 45°N (but below Region 2) (Table 1).

As described earlier, different experimental designs were used in the experiments and in order to carry out the analysis a number of assumptions were made (Appendix 1). In the initial analysis height, diameter and form data after 55 years from New Forest, Thetford and Radnor was analysed. In the second stage of the analysis the latest height data only from each of the six sites was combined and analysed. The response variables height and mean DBH 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 Poisson error distribution and logarithmic 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 three (or six) experiments (sites) each with between three and eight blocks (blocks) and the 13 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

- After 55 years, top height of the seed origins ranged between 22.5 m (Massett 1, Thetford) and 27.7 m (Sooke, Radnor) (Table 1).
- There were significant differences between the Seed Regions with the order being 2=3>1. This was the initial result for the 55 year data (Table 3) and was confirmed when the data from Alice Holt, Thornthwaite and Benmore was added into the analysis (Table 4).
- There were no significant differences between the three sites (Table 3) after 55 years.
- The estimates of top height were used to give an indication of GYC and these ranged between 16 and 22. Site productivity varied Radnor>New Forest>Thetford for the most recent assessments. The GYC for the other three sites was GYC18 or GYC20 but, because the trees were relatively young, the estimates are probably not as accurate (Table 1).

2.3.2 Diameter

- After 55 years mean diameters ranged between 33.5 cm (Region 1; Radnor) and 55.6 cm (Region 2; New Forest) (Table 5).

- There were significant differences between the Seed Regions with the order being 2=3>1.
- There were significant differences between sites but as Radnor, the most productive site, had the lowest diameter it is difficult to separate the effects of site and differences caused by thinning.

2.3.3 Form score

- Analysis showed no differences between form scores between the different Seed Regions (Table 6).

2.5 Conclusions

1. Western red cedar is a productive forest tree in Britain and achieved GYC16-22 on six sites with mineral soils but widely varying rainfall and temperature. This finding supports the analysis of Jinks (2017), that the yield of western red cedar does not vary much with moisture and temperature, and Minore's (1990) observation that red cedar does not vary as much as other conifers in its native range.
2. The results of this study suggest that the coastal region between 46°N and 50°N of Washington and British Columbia is the best area for future seed collection for use in Britain. Work to quantify the potential gain of using British provenances would be justified and could reveal some interesting results. This broadly supports the present advice on the FR species and provenance webpages, which is that 'western Washington or Vancouver Island should be preferred'. However, that published by Lines (1987; reproduced below) is somewhat different and keener to identify good local areas for seed collection rather than broad regions.
3. More work would be justified to quantify the relationship between site and yield to determine the limiting factors to growth in the Britain. There is good evidence that climate does not significantly affect the growth of western red cedar in Britain but factors such as soil type and exposure could be much more important and are poorly understood. Zehetmayr (1954) summarized early work on organic soils and suggested further work in mixture with pine would be justified. In terms of exposure, Savill (2013) suggests an upper planting limit of 200 m above sea level but the basis for this is uncertain.
4. The current FR Species and provenance webpages state that western red cedar 'may find an expanded role as a means of diversifying upland conifer forests as an adaptation to projected climate change'. The findings of this report, and the analysis of Jinks (2017), indicate that the species has potential on a wider range of sites than just the uplands. Wood (1955) judged that the species could be of 'of real importance in British forestry' (Appendix 3).

5. The work suggested on limiting factors on the growth of western red cedar (above) will help to give confidence to the Ecological Site classification Decision Support System indications of suitability and likely yield. In this study, ESC version 4 performed relatively well in this respect and certainly better than it did for noble fir (Kerr and McMinn 2018).
6. In addition, more work to confirm the timber properties of western red cedar is justified due to the small number of samples used in Ramsay and Macdonald (2013) and Gil-Moreno *et al*. (2016). There is little work reported in the literature on the characteristic features of the lower stem of red cedar, enhanced taper and fluting, and more work on these may lead to a better understanding of the causes and how these features that tend to reduce value could be controlled.

Extract from Lines (1987) on western red cedar

'Recommendations

1. First choice is the north slope of the Olympic Mountains, Washington (US Zone 221) below 150 m in elevation.
2. Some Vancouver Island seed sources (e.g. Ladysmith, BC Zone 1020) show promise.
3. The interior origin from Shuswap Lake (3040) grew well, except at Benmore.
4. Ashford (US Zone 422) is acceptable and showed high resistance to *Didymascella* in the forest.

Where the nursery has a history of *Didymascella* infection, fungicidal treatment with cyloheximide is still necessary for any seed origin.'

3.0 Tables and Figures

Table 1: Summary of the western red cedar seed origin locations and GYC* at the experiment sites

Seed origin	Location	Region	State	Lat. (°N)	Long.	Alt (m)	Dist to coast (miles)	New Forest	Thetford	Radnor
								Top height (m) and GYC		
58(7114)1	Terrace	1	BC	54.50	N/A	up to 150 m	60	24.3	24.9	25.0
58(7111)1	Massett 1	1	BC (QCI)	54.02	N/A	up to 150 m	0-10	24.0	22.5	23.1
56(7111)1	Massett 2	1	BC (QCI)	54.02	N/A	up to 150 m	0-10	23.0	25.1	22.7
58(7118)1	Shuswap Lake	2	BC	50.83	N/A	up to 450 m	240	25.7	25.4	27.1
58(7116)2	Courtenay	2	BC (VI)	49.70	N/A	up to 150 m	0-10	24.1	23.7	25.0
58(7116)1	Alberni	2	BC (VI)	49.23	N/A	up to 150 m	0-10	25.0	24.9	25.2
58(7116)4	Ladysmith	2	BC (VI)	49.02	N/A	up to 150 m	0-10	25.2	24.7	26.0
58(7116)3	Sooke	2	BC (VI)	48.36	N/A	up to 150 m	0-10	25.7	22.6	27.7
58(7971)2	Joyce	2	WA	48.17	N/A	up to 150 m	0-10	26.7	24.8	27.0
58(7973)2	Sequim	2	WA	48.13	N/A	up to 150 m	0-10	25.2	25.1	27.2
58(7975)2	Tenino	3	WA	46.75	N/A	up to 150 m	70	24.0	25.0	25.8
58(7975)6	Ashford	3	WA	46.58	N/A	up to 600 m	100	25.4	25.7	26.7
58(7953)3	Vernonia	3	OR	45.83	N/A	up to 230 m	30	22.6	25.2	26.1

Colour codes for GYC	
	22
	20
	18
	16

GYC	Site
	Alice Holt
	Thorn.
	Benmore

* GYC shown for each seed origin for recent assessments but only site GYC for Alice Holt, Thornthwaite and Benmore

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

Site	Lat. (°N)	Long. (°W)	P. Year	DAMS	AT5	SMR	SNR	Suitability	Ann. rainfall (mm)
New Forest	51	-1.7	1963	12	1864	5 (fresh)	5 (v. rich)	0.79 V. suitable	850
Thetford	52.5	0.62	1963	12	1804	6 (sl dry)	6 (carb)	0.66 Suitable	620
Radnor	52.3	-3.2	1963	12	1247	5 (fresh)	2 (poor)	0.66 Suitable	1100
Alice Holt	51.2	-0.9	1963	10	1826	5 (fresh)	3(Medium)	0.81 V. suitable	800
Thornthwait	54.6	-3.3	1963	15	1364	3(Very moist)	3(Medium)	0.59 Suitable	1160
Benmore	56	-4.9	1963	13	1242	5 (fresh)	2 (poor)	0.66 Suitable	2200

Site	Soil	Silviculture of establishment
New Forest	Clay loam (1)	Planted under 'tall' EL overstorey
Thetford	Podsol (3)	Underplanting of mature Scots pine
Radnor	Upland BE (1u)	Planted under EL overstorey (130 trees ha-1) that was felled in January 1969
Alice Holt	Clay loam (1)	Planted into 'dense' hazel coppice with some 8-12 m widely spaced broadleaves
Thornthwait	Upland BE (1u)	Initial P62 restocking failed; replanted in 1963 but heavy losses required beat-up in May 1964
Benmore	Upland BE (1u)	Established on a restock site

Table 3: Top height (m) of the red cedar seed origins by Region and site (3 sites)

Region	New Forest	Thetford	Radnor	Mean
1	23.8	23.6	24.1	23.57
2	25.4	26.4	24.5	25.39
3	24.0	26.2	25.3	25.26
Mean	24.5	24.2	25.6	
REML analysis showed that Region was significant (P=0.009) but Site was not (P=0.159). Means are modelled values (Region SED =0.51) whereas site x region data (shaded) are actual means.				

Table 4: Top height (m) of the red cedar seed origins by Region and site (6 sites)

Region	New Forest	Thetford	Radnor	Alice Holt	Thornthwaite	Benmore	Mean
1	23.8	23.6	24.1	5.2	6.7	6.7	14.95
2	25.4	26.4	24.5	5.6	7.4	7.3	16.06
3	24.0	26.2	25.3	5.8	7.2	7.2	16.02
Mean	24.5	24.2	25.6	5.4	7.1	7.0	
REML analysis showed that Region was significant (P<0.001) as well as Site (P=0.001); however, the latter result is highly influenced by the different ages of assessment between the six sites. Means are modelled values (Region SED=0.26) whereas site x region data (shaded) are actual means.							

Table 5: Mean diameter (cm) of the red cedar seed origins by Region and site

Region	New Forest	Thetford	Radnor	Mean
1	50.0	35.2	33.5	39.9
2	55.6	43.1	46.8	48.7
3	50.8	40.6	44.9	45.1
Mean	52.0	42.4	39.4	
REML analysis showed that Region (P=0.003) and Site (P=0.003) were both significant but the latter is probably due to differential thinning between sites. Means are modelled values (Region SED=2.0; Site=2.1) whereas site x region data (shaded) are actual means.				

Table 6: Mean form score of the red cedar seed origins by Region and site

Region	New Forest	Thetford	Radnor	Mean
1	1.0	1.7	2.5	1.6
2	1.0	1.8	2.2	1.6
3	1.0	1.7	2.2	1.5
Mean	1.0	1.7	2.3	
REML analysis showed that Site (P<0.001) was significant but Region was not (P=0.485); the result for Site is probably due to different interpretation of the scores between sites. All means are modelled values.				

Figure 1: The species range of *Thuja plicata* as shown in Lines (1987)

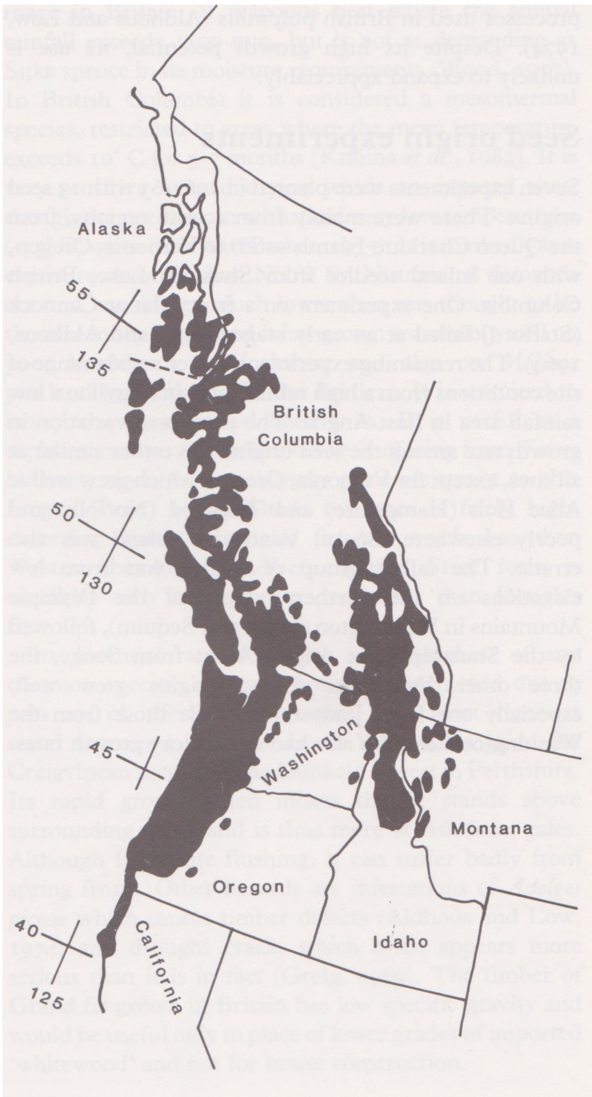
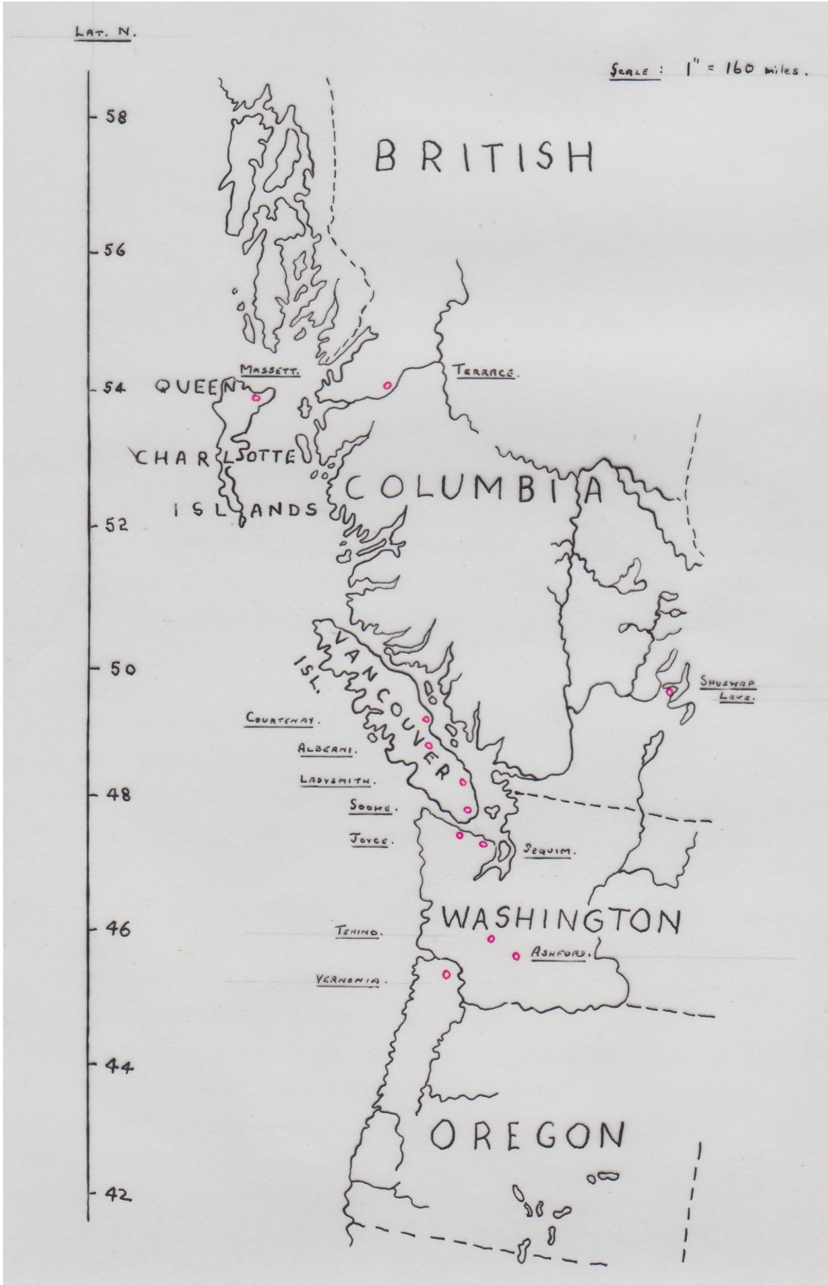


Figure 2: Map showing the approximate locations of the seed collections from Gregory (1969)



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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 Justin Gilbert who supplied the area figures for Britain.

Appendix 1: Note on experimental designs and approach to analysis

Experiment	Experiment design as shown in plan	Experiment design assumed for analysis
Alice Holt 127	The plan states '2 incomplete Latin Squares each 13 x 4' and this is supported by a diagram. 9 tree plots, 3 x 3	A randomised block experiment with 13 treatments (seed origins) and 8 blocks
Benmore 8	The data are structured to show 13 treatments in 13 incomplete blocks; each treatment (seed origin) has 4 replicates. 36 tree plots, 6 x 6	A randomised block experiment with 13 treatments (seed origins) and 4 blocks
New Forest 19	The plan shows 13 treatments (seed origin) in 3 complete blocks. 100 tree plots, 10 x 10	A randomised block experiment with 13 treatments (seed origins) and 3 blocks
Radnor 36	The plan states 'incomplete randomised block' and diagram shows 2 blocks each of 39 plots.	A randomised block experiment with 13 treatments (seed origins) each of which is replicated 3 times in the 2 blocks, i.e. 6 plots of each treatment (seed origins).
Thornthwaite 3	The data are structured to show 13 treatments in 13 incomplete blocks; each treatment (seed origin) has 4 replicates. 36 tree plots, 6 x 6	A randomised block experiment with 13 treatments (seed origins) and 4 blocks
Thetford 84	The plan states '6 reps, incomplete Latin square'. 8 tree plots, 2 x 4.	A randomised block experiment with 13 treatments (seed origins) and 6 blocks

Appendix 2: Note on previous analysis of experiments

The experiment plan suggests analysis of the data with the main factor in the analysis being 'distance from the coast' and grouped the 13 seed origins into three (coastal, intermediate, inland) as shown in the table below. However, none of the analyses in the experiment files has followed this plan (see text below the table). In the current study this was checked by replacing 'Region' with 'Coastal zone' in the analysis. The result was that there were no significant differences between the three 'distance from coast' zones. This is not surprising as close examination of Figure 2 shows that only one of the seed origins is from an area where there would be no or little influence of the coast.

Seed origin	Location	Coastal zone	State	Lat. (^{o}N)	Dist to coast (miles)
58(7114)1	Terrace	Intermediate	BC	54.50	60
58(7111)1	Massett 1 - QCI	Coastal	BC	54.02	0-10
56(7111)1	Massett 2 - QCI	Coastal	BC	54.02	0-10
58(7118)1	Shuswap Lake	Inland	BC	50.83	240
58(7116)2	Courtenay	Coastal	BC (VI)	49.70	0-10
58(7116)1	Alberni	Coastal	BC (VI)	49.23	0-10
58(7116)4	Ladysmith	Coastal	BC (VI)	49.02	0-10
58(7116)3	Sooke	Coastal	BC (VI)	48.36	0-10
58(7971)2	Joyce	Coastal	WA	48.17	0-10
58(7973)2	Sequim	Coastal	WA	48.13	0-10
58(7975)2	Tenino	Inland	WA	46.75	70
58(7975)6	Ashford	Inland	WA	46.58	100
58(7953)3	Vernonia	Intermediate	OR	45.83	30

An analysis of the data from Benmore carried out on the 17 year height data in the experiment file did not use the distance from coast factor suggested in the experiment plan. Instead five locations (see the 'State' column in Table 1) were compared using analysis of variance. This showed that there were no differences between seed origins within each location but there was a significant difference between groups (P<0.001). Results showed that Washington (735 cm) and Vancouver Island (728 cm) had better growth than from the interior of British Columbia (702 cm) and Oregon (692 cm); origins from the Queen Charlotte Islands were the shortest (654 cm).

Appendix 3: Observations on western red cedar by Wood (1955)

The following text is taken from the wonderful Forestry Commission Bulletin 22:

'**Thuja plicata**

Some mention must be made of *Thuja plicata* if only because it is such a widespread and typical species in the Coastal Forest. But I found it very difficult to understand its status in the forest. It seems to be present in all conditions from the best to the worst. It makes often the best showing on poor sites bordering on muskeg conditions*, on the other hand it is almost certain to be present also on the best alluvial sites. Its one obvious advantage on the latter lies in its longevity, which includes the power of surviving gross injuries from fire and other causes. Hence a few individuals scattered about can provide a seed source for a very long time indeed, during which mere chance may get some of their progeny into a favourable position. But it is only at the poorer end of the scale that it is likely to *dominate* its associates by a better general response. One would guess that its fertility requirements are slightly lower than those for hemlock, but its moisture requirements appear rather higher. On the whole it is a species which one would expect to be of real importance in British forestry – sited on the poorer parts of the present range of Sitka spruce, but not with the same degree of confinement on the grounds of moisture.'

* This observation led to trialling of the species on wet peats in Britain, see Zehetmayr (1954)

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