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Variation in Growth of 20-Year-Old Provenance Trial of Sitka spruce (*Picea sitchensis* (Bong.) Carr.) in Great Britain

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Abstract : Variation in growth of the cambial age (tree diameter) and tree volume was investigated in eight seed origins of Sitka spruce (*Picea sitchensis* (Bong.) Carr.) grown at two sites in Great Britain. The trial seed origins were collected from 58°N to 41°N latitude, 134°W to 123°W longitude, and 0 m to 140 m altitude in the natural range of Sitka spruce that extends in a narrow coastal strip from Alaska to California (Alaska -AL, British Columbia -BC, Queen Charlotte Islands -QCI, North Washington -NW, South Washington -SW, North Oregon -NO, South Oregon -SO, California -CA). The experimental plantations were raised at Dalby in north-east England (53°N, 0°W, 183 m) and Rhondda in south Wales (51°N, 3°W, 450 m). Five trees of each seed origin at each site were sampled at three heights (1, 2 and 3 m above ground level). The influences of tree diameter and tree volume on the growth rate were analysed within and between tree variations and also between seed origins. The results showed that the trees had less taper but had a larger diameter in Dalby than in Rhondda and this directly affected tree volume. The faster growing Dalby trees consequently had higher tree volume than the slower growing Rhondda trees. It was also found that AL grew poorly at both sites, it may be therefore suggested that this seed origin should be avoided in the future plantations. However, QCI, CA, SW and NO should be selected for more plantations at both sites as all grow well with a good growth rate. SO in Dalby and SW in Rhondda showed the fastest growth, and therefore these can be selected for individuals with high volume production.

Key Words: Sitka Spruce, Site-Seed Origin-Provenance, Growth Rate-Tree Volume-Tree Diameter at Breast Height

Büyük Britanya'da 20 Yaşındaki Sitka Ladini (*Picea sitchensis* (Bong.) Carr.) Orijin Denemesinde Büyümenin Değişimi

Özet : Belirli bir yaşa kadar olan çap büyümesi ve hacim gelişmesi, Büyük Britanya'da iki farklı deneme alanında yetiştirilmekte olan Sitka ladini (*Picea sitchensis* (Bong.) Carr.) türünün sekiz ayrı tohum orijini çerçevesinde incelendi. Denemede kullanılan tohum orijinleri Sitka ladini'nin doğal yetişme kuşağı olan 58°-41° Kuzey enlemleri ve 134°-123° Batı boylamları arasındaki Alaska ile Kaliforniya arasındaki dar kıyı bölümünden 0-140 m yükseltideki sekiz bölgeden toplandı (Alaska -AL, British Columbia -BC, Queen Charlotte Islands -QCI, North Washington -NW, South Washington -SW, North Oregon -NO, South Oregon -SO, California -CA). Bu çalışmada, Kuzey-Doğu İngiltere'nin Dalby (53°N, 0°W, 183 m) ve Güney Galler'in Rhondda (51°N, 3°W, 450 m) deneme alanlarındaki tohum orijinlerinden yetiştirilmiş beşer adet ağaç seçilerek bunların toprak düzeyinden 1,2 ve 3 m yüksekliklerinden alınan deney malzemesi üzerinde ölçümler yapıldı. Ağaç çapı ile ağaç hacminin büyüme derecesine olan etkileri ağaçların kendileri içerisinde, birbirleri arasında ve ayrıca tohum orijinleri arasında analiz edildi. Araştırma sonuçları, ağaç hacmine doğrudan etki eden bir faktör olarak Dalby deneme alanında yetiştirilen ağaçların Rhondda'dakilere göre daha dolgun ve daha kalın çaplı olduğunu gösterdi. Bu nedenle, hızlı büyüme özelliği gösteren Dalby ağaçları yavaş büyümekte olan Rhondda ağaçlarına göre daha yüksek hacim gelişmesi sağladı. Araştırma sonuçları ayrıca, tohum orijini AL'ın her iki deneme alanında da oldukça yetersiz geliştiğini belirledi ve dolayısıyla bu tohum orijininin gelecekteki yetiştirme çalışmalarında kullanılmaması önerildi. Bunun yanında, iyi büyüme dereceleriyle yeterli gelişme yaptıklarından QCI, CA, SW ve NO her iki deneme alanında da daha fazla yetiştirilmek için seçilebilirler. Dalby'den SO ve Rhondda'dan SW yine hızlı büyüme özelliği içerisinde olduklarından yüksek hacimde odun hammaddesi üretimi amacıyla sadece kendi deneme alanları için seçilebilirler.

Anahtar Sözcükler: Sitka Ladini, Deneme Alanı-Tohum Orijini-Yetişme Yeri, Büyüme Derecesi-Ağaç Hacmi-Göğüs Yüksekliğindeki Ağaç Çapı

Introduction

Sitka spruce (*Picea sitchensis* (Bong.) Carr.), a species of the western seaboard of North America from southern Alaska to northern California, is the best adapted tree for growing in the wet upland parts of Great Britain (1, 2), and is the only British softwood of commercial importance which produces an almost uniformly pale-coloured wood described as whitewood from southern Scandinavia (Norway spruce, *Picea abies*) and parts of northern and central Europe (3).

It was mostly planted in the north and west of Britain, in some areas comprising 90 per cent of all trees planted (4). Current planting consists of Sitka spruce and it is likely that it will continue to be planted on a large scale. There are now over 600,000 hectares of Sitka spruce in the UK, comprising approximately 27 per cent of the total area under coniferous forest (4).

Sitka spruce is favoured because it is readily established, grows on a wide variety of sites, is tolerant of severe levels of exposure, is generally disease resistant, has a good stem form and gives a higher yield than most other species, particularly on less fertile sites (5, 3). Most British plantation Sitka spruce is fairly fast growing and British timber is generally regarded as being only marginally acceptable for construction grade timber. The timber is light in weight and coarse in texture, has numerous large knots, and a relatively low density (i.e., average density at 12 % moisture content is the region of 390 kgm^{-3} but wood density of this species varies considerably with distance from the pith, with height of the tree, between trees and with silvicultural management and site class) (3).

An intensive breeding programme has been carried out in Sitka spruce for more than 30 years with the aim of improving the vigour, form and timber quality of the tree crop (6). Until recently, the main objectives of breeding were to increase volume growth rates and timber yields. Wood density is now considered in the breeding programme as well. Tree improvement is a combination of silviculture and tree breeding aimed at producing higher quality products. The tree breeding contribution consists of producing superior genotypes but these cannot fulfil their optimal potential unless appropriate silvicultural treatments are implemented. Genetic improvement of a species by breeding depends on the amount of genetic variability which is exhibited across its natural range and at the individual tree level.

There are three levels of genetic variability which the tree breeder can utilise, namely: species, provenance* (seed origin) and individual tree. In any tree breeding programme these three levels are to be exploited in that order (7).

The seed origin testing phase has indicated that there are differences between seed origins in growth rates, phenology and wood properties and that by selecting the correct seed origin gains can be achieved. In this work, therefore, the growth patterns between and within seed origins were studied at the more favourable trial sites to identify the most suitable seed origins for British conditions.

Materials and Methods

The Seed Origins Sampled and Trial Sites: The study was carried out on 80 twenty-year-old trees from eight seed origins (Table 1) of Sitka spruce grown at two experimental sites: Rhondda in south Wales and Dalby in north-east England. All the trees were growing in a IUFRO (International Union of Forest Research Organisation) seed origin trial planted in 1975. Eight seed origins from throughout the whole distribution of the species from north to south were chosen for this study. The two sites represent extremes of the range of sites on which this species is used in Britain, and were chosen for this reason. The geographical locations of the selected seed origins and the general characteristics of the trial sites are presented in Tables 1 and 2 respectively. A map of the natural distribution of Sitka spruce is shown in Figure 1, which also includes a map of Great Britain with the site locations.

Selection of Sample Trees and Collection of Field Data: Following an appraisal of the site, five trees of each of the eight seed origins (a total of 40 trees from each site) were selected for good butt form, circular cross-section, uniform crown development, freedom from root influence extending up the tree, and freedom from sweep and drought cracks, in anticipation of their yielding timber of normal growth at breast height. Trees of average diameter for each seed origin were chosen and any trees with obvious double leaders, uneven crowns or other major irregularities in the stem were rejected. The selected trees were felled in January (Rhondda) and February (Dalby) of 1995 at 50 cm above ground level and the lower 9 m of each tree was then cut into 3 m

* According to European Community definitions, provenance is the place in which any stand of trees (whether native or not) is growing, and origin is the place in which a stand of native trees is growing, or the place from which a non-native stand was originally introduced. In general forestry use, the term provenance is commonly extended to mean not only the geographical source of the seed, but also the trees raised from it. This is the meaning in accord with the definition in the standard works on forest terminology [8].

Region	Seed Origin	Latitude (N)	Longitude (W)	Elevation (m)
Alaska	Duck Creek, Juneau Area	58° 37`	134° 58`	30
British Columbia	Inverness, Prince Rupert	54° 20`	130° 25`	0 - 30
Queen Charlotte Islands	Masset (Commercial Seedlot)	54° 00`	132° 00`	0 - 15
North Washington	Forks, Olympic Rain Forest	48° 07`	124° 30`	120 - 140
South Washington	Raymond, Willapa Bay	46° 68`	123° 87`	15 - 30
North Oregon	Necanicum	45° 82`	123° 77`	45
South Oregon	Brookings, Oregon	42° 25`	124° 38`	90
California	Crescent City, California	41° 67`	124° 18`	10 - 15

Table 1a. Geographical locations of the experimental seed origins (arranged north to south along the natural distribution of Sitka spruce).

Region	MRN	IUFRO (no)	FC (no)
Alaska	3	3024	70 (7987) 101
British Columbia	20	3044	70 (7112) 103
Queen Charlotte Islands	37	7111	70 (7111) Lot2
North Washington	53	3003	68 (7971) 100
South Washington	59	3009	68 (7972) 102
North Oregon	62	3012	68 (7951) 101
South Oregon	68	3018	68 (7952) 102
California	70	3020	69 (7947) 101

MRN = map reference number used in Figure 1., FC = Forestry Commission seed identification number
IUFRO = International Union of Forest Research Organisation seed identification number.

Table 1b. Identification numbers of the selected seed origins.

Characteristic	Dalby	Rhondda
Year of establishment	1975	1975
NGR (National Grid Reference)	SE882849	SN940019
elevation (m)	183	450
Rainfall (mm/year)	835	2400
Exposure	Severe	Severe
lithology (geology)	soft limestone	Carboniferous sandstone
Soil type	ironpan	Molinia/calluna bog
Forest site type (previous use)	Open moorland	Uncultivated hill pasture land
Site preparation (cultivation)	Complete ploughing	Single furrow tine ploughing
Fertilisers	375 kg/ha Gafsa	375 kg/ha Gafsa
Spacing (planting)	2 x 2 m	2 x 2 m
Design	Randomised blocks	Randomised blocks
Replication	4	2
Plot size	Square plot 3 x 3 (9) tree - STS	Square plot 3 x 3 (9) tree - STS
Seed origins	64	34
dominant ground vegetation	rubus spp., Rosa spp., Deschampsia flexuosa	juncus spp., molinia caerulea

• The trial sites Dalby and Rhondda are indicated as D and R respectively in Figure 1,
• STS = short thinning section

Table 2. General characteristics of trial sites at Rhondda (Wales) and Dalby (England).

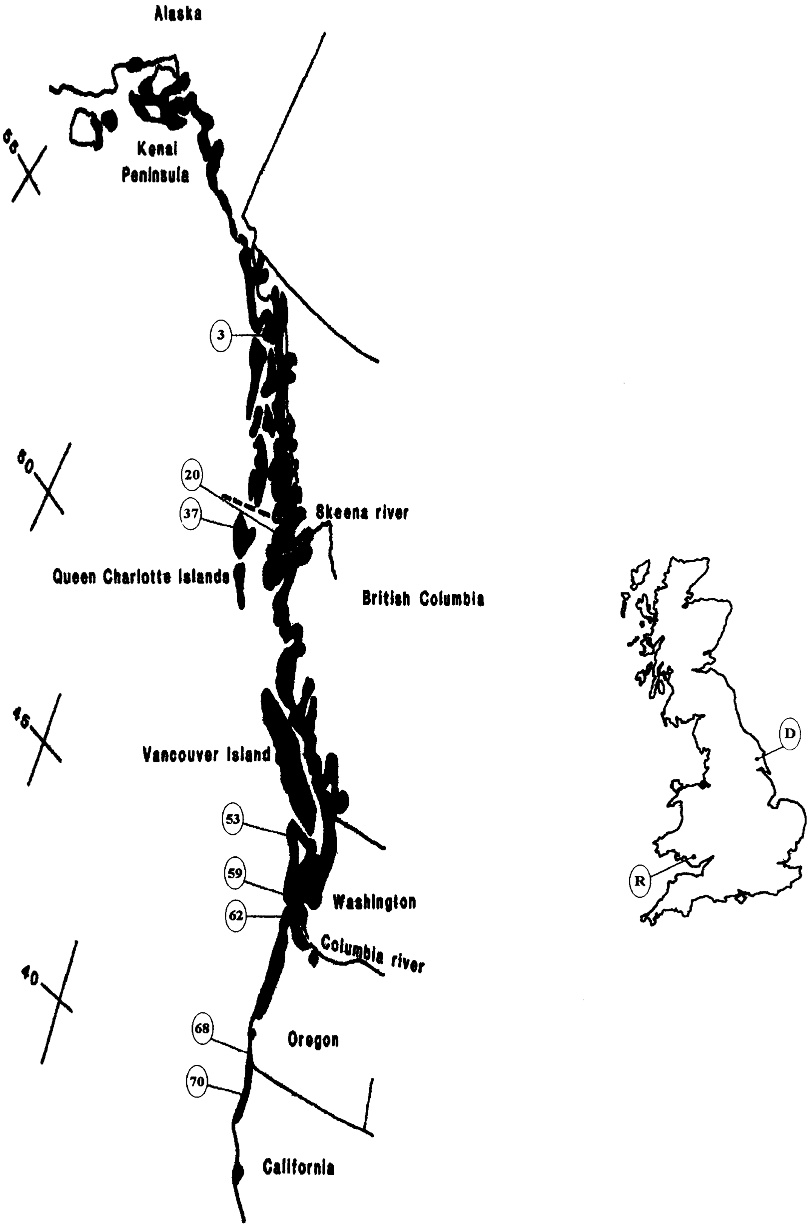

Figure 1. (a) Natural distribution of Sitka spruce (*Picea sitchensis* (Bong.) Carr.) with locations of selected seed origins, (b) Locations of trial sites in Great Britain.

lengths and marked to assist in identification. After felling and prior to conversion, the mean diameter at breast height (DBH) was measured (according to Philip (9), DBH is 130 cm above ground level). The stem diameter was also measured and recorded at the base (50 cm), centre (200 cm) and top (350 cm) of the trees to enable later calculation of tree volume. The trees were labelled with their dimensions.

Statistical Analysis: All statistical analysis was conducted using the statistical package MINITAB, version 10.51 (Minitab Inc. Minitab for Windows, 1995). Arithmetic calculations and graphical designs were performed using the spreadsheet program Excel 5.0 for Windows. The diameter and volume data were tested for normality using the Ryan-Joiner test (Minitab 10.51). The normal scores of the data were compared with the experimental data by correlation analyses. The hypothesis of normality was rejected if the calculated correlation coefficient was below a critical value obtained from tables. Minitab was also used for analysis of variance (ANOVA) and for regression analyses. Tukey pairwise comparison tests were performed to identify significant differences between treatment means. Balanced analysis of variance (Balanced ANOVA) was also used to examine the relative importance of the factors influencing the tree volume with all possible interactions. It was possible to fully analyse this dataset beyond the calculation of sums of squares because there were no missing values in subclasses for three and four way interactions.

Results and Discussion

Individual tree parameters measured immediately after felling were recorded and are given in Table 2a. All these data are listed against seed origins similar the natural distribution of Sitka spruce from north to south (from Alaska to California). The results are shown as overall means for each seed origin at both sites.

Tree diameters at breast height (DBH) varied from 13.2 cm with Alaska (AL) to 16.5 cm with Queen Charlotte Islands (QCI) followed by 16.2 cm with California (CA). Mean diameters at the base and the top height on the sampled trees ranged from 13.7 cm to 17.1 cm and 9.2 cm to 13.1 cm, respectively. The seed origin AL showed the smallest tree volume (TV) with some 1.72 m^3 whereas CA showed the largest TV by 2.25 m^3, followed by 2.24 m^3 with QCI. This was therefore reflected in the middle diameters, which were the highest in QCI (14.8 m^3), followed by CA (14.7 m^3), and the lowest in AL (11.5 m^3).

These results can also be examined by site, e.g. Dalby and Rhondda (Tables 2b and 2c, respectively). The means shown here comprise to the data from 5 trees per seed origin and 3 heights per tree in each trial site. The full results are given in Appendix 1 (for Dalby and Rhondda).

Table 2a. The overall means of the variables for both Rhondda and Dalby.

	diameters within stem height (cm)			mean of the parameters		
overall	base 50 cm	middle 200 cm	top 350 cm	CAD (cm)	DBH (cm)	TV (m^3)
Alaska	13.7	11.5	9.2	11.4	13.2	1.72
British Columbia	15.4	13.5	11.6	13.4	15.0	2.01
Queen Charlotte Islands	17.1	14.8	12.9	14.9	16.5	2.24
North Washington	14.9	13.1	11.0	13.0	14.7	1.98
South Washington	15.1	13.4	11.9	13.3	14.7	2.06
North Oregon	14.9	12.9	11.1	12.9	14.6	1.93
South Oregon	14.8	13.1	11.6	13.2	14.4	1.98
California	16.5	14.7	13.1	14.8	16.2	2.25
mean	15.3	13.4	11.5	13.4	14.9	2.02

CAD = calculated average diameter, DBH = diameter at breast height (1.3 m above ground level), TV = tree volume

Table 2b. Means of the variables for trial site Dalby.

	diameters within stem height (cm)			mean of the parameters		
Dalby	base 50 cm	middle 200 cm	top 350 cm	CAD (cm)	DBH (cm)	TV (m^3)
Alaska	12.7	11.5	10.1	11.3	12.7	1.75
British Columbia	15.4	14.2	13.3	14.1	15.4	2.18
Queen Charlotte Islands	17.6	16.5	15.2	16.2	17.6	2.53
North Washington	15.1	13.9	12.3	13.8	15.1	2.12
South Washington	14.6	13.6	12.8	13.3	14.6	2.10
North Oregon	14.0	12.9	11.8	12.6	14.0	1.97
South Oregon	14.8	14.0	12.8	13.7	14.8	2.15
California	16.5	15.6	14.9	15.8	16.5	2.40
mean	15.4	14.3	13.3	14.2	15.4	2.17

	diameters within stem height (cm)			mean of the parameters		
Rhondda	base 50 cm	middle 200 cm	top 350 cm	CAD (cm)	DBH (cm)	TV (m^3)
Alaska	14.7	11.6	8.4	11.5	13.8	1.73
British Columbia	15.4	12.8	10.0	12.7	14.7	1.92
Queen Charlotte Islands	16.6	13.2	10.6	13.6	15.4	1.99
North Washington	14.8	12.3	9.7	12.2	14.4	1.85
South Washington	15.7	13.3	11.0	13.3	14.8	2.01
North Oregon	15.9	13.0	10.5	13.2	15.3	1.96
South Oregon	14.9	12.2	10.4	12.7	14.0	1.86
California	16.5	13.9	11.3	13.9	15.9	2.10
mean	15.6	12.9	10.5	13.0	14.9	1.96

Table 2c. Means of the variables for trial site Rhondda.

The tree growth varied significantly among most of the seed origins at both sites. The diameter (DBH) varied from 12.7 cm to 17.6 cm in Dalby, and 13.8 cm to 15.9 cm in Rhondda. At both sites, the seed origin Alaska (AL) had the narrowest tree diameter while the widest was Queen Charlotte Islands (QCI) followed by California (CA) in Dalby, and was CA followed by QCI in Rhondda. Mean diameter (cm) at the base height (50 cm above ground level) was largest in seed origin QCI followed by CA at both sites (Dalby: 17.6, 16.5; Rhondda: 16.6, 16.5) with the greatest growth rate. mean diameter at the top height (350 cm above ground level) was largest in seed origin QCI in Dalby (15.2) followed by CA (14.9), which was the highest one in Rhondda (CA: 11.3) followed by South Washington (11.0) and QCI (10.6). On the other hand, the smallest tree diameter at either the base or the top height of the stem was the seed origin AL at both trial sites: 12.7 to 10.1 at Dalby and 14.7 to 8.4 at Rhondda. Mean tree diameter at the middle height (200 cm above ground level) of the stem directly influenced tree volume values. The seed origins QCI and CA in Dalby and CA, SW and QCI in Rhondda, which both had the wider diameter at that level, also had the greater tree volume (Dalby: QCI = 2.53, CA = 2.40, Rhondda: CA = 2.10, SW = 2.01, QCI = 1.99), whereas AL, which had the lowest diameter at the middle level, also had the lowest tree volume at either of the trial sites Dalby (1.75) or Rhondda (1.73). The seed origin North Oregon (NO) in Dalby and North Washington (NW) in Rhondda both showed overall the second lowest tree diameter at all levels of the stem and tree volume (1.97 m^3 and 1.85 m^3, respectively).

Analysis of Variance: Table 3 shows the analysis of variance for tree volume and tree diameter at breast height (DBH). There were very highly significant ($p \leq 0.05$) effects of the site, seed origin, site x seed origin, and tree among the tree volumes. All of these were also significant effects among the DBH whereas there was no effect of site only.

Table 3. Analysis of variance for tree volume and tree diameter at breast height.

		tree volume			tree diameter at breast height		
Source	df	MS	F	p	MS	F	p
Site	1	1.021	78.30	0.000	1.984	2.51	0.119
Seed Origin	7	0.276	21.16	0.000	10.842	13.20	0.000
Site x Seed Origin	7	0.079	6.07	0.000	3.362	4.25	0.001
Tree	4	0.604	46.33	0.000	25.844	32.66	0.000
Error	60	0.013			0.791		

As shown in Table 4, there were significant differences (p = 0.000) in tree volume between the sites where Dalby (2.17 m^3) was greater than Rhondda (1.96 m^3). However, tree diameter at breast height (DBH) was not different (p = 0.434) between the sites (Dalby: 15.4 cm, Rhondda: 14.9 cm). According to the overall means of tree volume, the results generally indicate that the material from California (CA) and Queen Charlotte Islands (QCI) had the higher tree volume and DBH followed by South Washington (SW) and British Columbia (BC), while the rest had the lower amount in both cases. The highest tree volume (m^3) occurred in CA (2.25), followed by QCI (2.24), SW (2.06), BC (2.01), NW (1.98), SO (1.98) and NO (1.93), whereas the lowest volume was found in AL (1.73). On the other hand, the largest DBH (cm) was in QCI (16.5), followed by CA (16.2), BC (15.0), SW (14.7), NW (14.7), NO (14.6), and SO (14.6) whereas AL (13.2) had the smallest one. It also seemed that although the differences of either tree volume or DBH between AL and QCI, AL and CA were statistically significant, there were no other significant differences between the other seed origins.

The greatest tree volume (m^3) in Dalby was in QCI (2.53), followed by CA (2.40), whereas it was the lowest in AL (1.75). the descending order of tree volume for the others was BC (2.18), SO (2.15), NW (2.12), SW (2.10) and NO (1.97). The average tree volume of AL was lower than all the other seed origins but only the differences between AL and QCI, and AL and CA were statistically significant. Furthermore, there was a significant difference between tree volume in the seed origins QCI and NO. Although NO and CA may appear to be different to each other, this difference was not statistically significant. The highest tree volume (m^3) in Rhondda was in CA (2.10) followed by SW (2.01), QCI (1.99) and NO (1.96), whereas it was the lowest in AL (1.73). the descending order of tree volume for the remaining seed origins was BC (1.92), SO (1.86), and NW (1.85). It appears that there were no statistically significant differences in tree volume between the seed origins of Rhondda.

Tree Volume / *Site x Seed Origin - Interactions*: Interactions between origins and sites are highlighted by ranking origins in descending order of tree volume at each site. As seen in Figure 2, seed origins were individually higher at one site than another and the descending order of the volumes varied between the sites. For instance, the mean volumes of the Dalby trees of BC, SO and NW were significantly higher than those of the Rhondda trees, whereas the seed origins of SW and NO were greater in Rhondda than in Dalby. Furthermore, both QCI and CA showed higher, and AL lower tree volume at both sites.

Table 4. Pairwise differences in tree volume (m3) and DBH (cm) between seed origins.

	tree volume			tree diameter at breast height		
Seed Origin	Dalby	Rhondda	overall	Dalby	Rhondda	overall
Alaska	1.75ad	1.73a	1.72a	12.7ad	13.8a	13.2a
British Columbia	2.18ab	1.92a	2.01ab	15.4ab	14.7a	15.0ab
Queen Charlotte Islands	2.53be	1.99a	2.24bc	17.6be	15.4a	16.5bc
North Washington	2.12abc	1.85a	1.98ac	15.1abc	14.4a	14.7ac
South Washington	2.10ab	2.01a	2.06ac	14.6ab	14.8a	14.7ac
North Oregon	1.97cd	1.96a	1.93ac	14.0cd	15.3a	14.6ac
South Oregon	2.15ace	1.86a	1.98ac	14.8ace	14.0a	14.4ac
California	2.40bc	2.10a	2.25bc	16.5bc	15.9a	16.2bc
• • mean	2.17	1.96	2.02	15.4	14.9	14.9

• Means that are not significantly different from each other at P<0.05 level have the same letter in a given column (e.g. tree volume at Dalby, British Columbia 2.18ab is not significantly different to California 2.40bc)

• • Overall means of each site for tree volume are significantly different from each other at P<0.05 level,

• • Overall means of each site for tree diameter at breast height are not significantly different from each other at P<0.05 level.

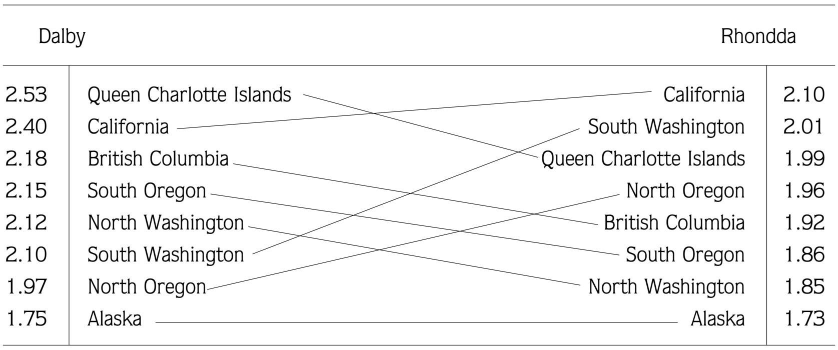

Figure 2. Site x Seed Origin interactions for tree volume.

Conclusion

Comparison of the two sites suggests that the trees had less taper but had a larger diameter in Dalby than in Rhondda and this directly affected tree volume. Consequently, for comparable parameters, the faster growing Dalby trees had higher volume than the slower grown Rhondda trees. Differences in tree volume between seed origins grown at the same site are also dependent on the site conditions that control the growth rate of the seed origins as a result of the properties of the soil (fertility, depth, moisture retention) and the climate (temperature, photoperiod, light intensity, rainfall), which are both significantly affected by altitude (10). Between the seed origins at trial sites in this study, significant differences were evident in both tree volume and tree diameter at breast height, which were greater at Dalby than at Rhondda as a result of a lower elevation at Dalby (183 m) than at Rhondda (450 m). Moreover, the soil type was different in Dalby (Ironpan) and Rhondda (*Molinia/Calluna* bog).

As mentioned by Fletcher (7), the results of IUFRO seed collection experiments in 1969/70 have indicated that there were differences between seed origins in growth rates, phenology and wood properties and that by selecting the correct seed origin gains can be achieved. The QCI origins were good general purpose sources, which were reasonably frost hardy, resistant to exposure and produce acceptable timber. At less exposed, more favourable sites, especially in south-west England, Wales and parts of west Scotland, origins from Washington and at some sites Oregon could be used with increases in timber production but with the possibility of a slight decrease in strength properties. In this case, the trees originating from CA (at both sites) and SO (Dalby) were found to grow much faster than would be expected from their latitude of origin, while those from BC (Dalby) were much more vigorous than expected (Table 4). Further, as was initially shown by Lines (4), it was also found in this study that seed origin AL grew poorly at both sites. It may be therefore suggested that this seed origin should be avoided in the future plantations. However, QCI, CA, SW and NO should be selected for more plantations at both sites as all grow well with a good growth rate (Figure 3). On the other hand, the seed origins BC, SO and NW in Dalby, and SW in Rhondda showed the fastest growth, and therefore these can selected for individuals with high volume production.

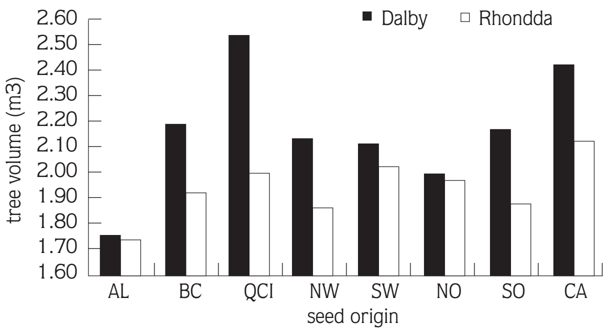

Figure 3. The variation of tree volume between seed origins at Dalby and Rhondda.

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Appendix 1. Diameters (cm) (in above table) and volumes (m^3) (in below table) of the five sampled trees (T1, T2, T3, T4, T5) for each seed origin at trial sites Dalby and Rhondda.

		Dalby						Rhondda					
Seed Origin	Stem Height	T1	T2	T3	T4	T5	mean	T1	T2	T3	T4	T5	mean
	top	9.2	9.7	9.6	9.9	12.5	10.1	8.0	7.0	8.4	9.0	10.0	8.4
Alaska	middle	10.5	10.2	11.2	11.7	14.0	11.5	10.6	10.4	12.0	12.8	12.6	11.6
	base	12.2	11.8	12.1	12.6	14.9	12.7	13.0	14.4	15.3	15.5	15.3	14.7
	top	12.0	11.8	12.9	14.1	15.7	13.3	9.0	9.0	10.0	10.0	12.0	10.0
British Columbia	middle	12.7	12.8	13.3	15.2	17.2	14.2	11.6	12.4	12.5	12.7	15.0	12.8
	base	13.2	14.0	14.7	17.2	18.0	15.4	14.1	15.1	15.0	15.2	18.0	15.4
	top	14.3	13.6	15.3	16.0	16.8	15.2	9.3	9.4	11.4	11.0	12.0	10.6
Queen Charlotte Islands	middle	14.7	16.0	16.3	17.1	18.8	16.5	11.7	11.8	14.3	13.1	15.1	13.2
	base	15.4	17.0	18.1	18.4	19.5	17.6	14.2	14.6	17.5	17.9	18.9	16.0
	top	11.9	12.2	12.6	12.5	12.6	12.3	9.7	9.0	9.1	10.5	10.5	9.7
North Washington	middle	13.1	13.4	13.8	15.0	14.4	13.9	12.3	11.7	12.0	12.5	13.2	12.3
	base	14.7	14.8	14.5	15.9	16.0	15.1	14.0	14.7	15.0	14.3	16.0	14.8
	top	10.6	12.9	12.5	14.0	14.0	12.8	10.0	11.0	11.2	11.5	11.5	11.0
South Washington	middle	12.0	12.8	14.0	14.8	14.7	13.6	11.5	11.9	13.4	14.3	15.5	13.3
	base	12.5	14.7	14.6	15.4	16.0	14.6	13.4	15.2	15.8	16.4	17.8	15.7
	top	8.2	10.9	11.7	13.2	15.3	11.8	9.9	9.8	9.7	11.3	12.0	10.5
North Oregon	middle	9.4	12.0	12.6	14.0	16.5	12.9	12.8	12.6	12.9	12.7	14.0	13.0
	base	11.5	12.5	13.6	14.9	17.5	14.0	15.4	15.9	16.3	16.0	16.0	15.9
	top	11.8	11.4	11.6	14.5	14.7	12.8	8.5	10.0	10.4	11.4	12.1	10.4
South Oregon	middle	12.7	12.3	13.0	16.0	16.4	14.0	10.5	12.6	11.8	13.0	13.3	12.2
	base	13.4	13.2	13.7	16.7	17.0	14.8	13.1	14.3	14.5	16.2	16.5	14.9
	top	13.5	13.8	14.4	16.3	16.5	14.9	9.4	11.5	12.3	11.7	12.0	11.3
California	middle	14.3	15.0	15.2	16.5	17.0	15.6	11.1	13.6	14.6	14.5	16.0	13.9
	base	15.7	16.0	16.0	16.9	18.3	16.5	12.8	16.9	16.4	17.4	19.4	16.5

		Dalby						Rhondda					
	Seed Origin	T1	T2	T3	T4	T5	mean	T1	T2	T3	T4	T5	mean
	Alaska	1.60	1.57	1.69	1.76	2.13	1.75	1.58	1.53	1.77	1.88	1.89	1.73
	British Columbia	1.95	1.96	2.06	2.33	2.63	2.18	1.73	1.83	1.88	1.90	2.25	1.92
	Queen Charlotte Islands	2.27	2.41	2.51	2.62	2.86	2.53	1.75	1.77	2.15	1.99	2.27	1.99
tree volume	North Washington	2.00	2.05	2.11	2.25	2.19	2.12	1.84	1.75	1.79	1.89	1.98	1.85
(m^3)	South Washington	1.82	2.00	2.13	2.27	2.26	2.10	1.75	1.83	2.02	2.14	2.29	2.01
	North Oregon	1.43	1.83	1.93	2.15	2.53	1.97	1.91	1.89	1.92	1.94	2.12	1.96
	South Oregon	1.95	1.88	1.98	2.44	2.49	2.15	1.58	1.88	1.80	1.98	2.04	1.86
	California	2.20	2.29	2.34	2.55	2.63	2.40	1.68	2.06	2.20	2.18	2.38	2.10
	mean	1.90	1.99	2.09	2.29	2.46	2.15	1.72	1.81	1.94	1.98	2.15	1.92