Forest Research

Summary of FR Seed Origin Trials on Low's fir [*Abies concolor* var. *lowiana (Gord.) Lemm.*]

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The Research Agency of the Forestry Commission

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Front cover pictures: (left) Low's fir at the experiment Mortimer 11; (right) Low's fir at the experiment Honiton 2.

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Executive summary

Low's fir (*Abies concolor* var. *lowiana*) is the western form of *Abies concolor*. It occupies sites between 1200 m and 2100 m in the Sierra Neveda and then sites at lower elevations to the north up to an ill-defined area in the Oregon Cascades. At the northern end of the range it intergrades with *Abies grandis* and at the southern limit it merges with the other variety of *Abies concolor* (*Abies concolor* var. *concolor*). In its natural range the species is very shade tolerant and can grow well on a wide range of soil conditions, nutrient availabilities and pH values. It can achieve high rates of growth and produces construction grade timber.

There is little experience of using Low's fir in British forestry although good growth and form have been reported from specimen trees (Mitchell, 1979). In 1968, five seed origin experiments were established by the Forestry Commission to study its growth relative to grand fir. A review of the experiments after 10 years concluded that grand fir was the best performer (on the basis of height growth) and all but one of the trials was closed. The experiments were re-examined in 2015 and two of them were found to be complete and were assessed for height, diameter and form after 47 years.

The main results of the analysis were:

- Estimated yield classes for Low's fir ranged between GYC 12-28 and grand fir GYC 28-30.
- There were no significant interactions between seed origin and site and therefore advice on choice of seed origin probably does not have to be site specific.
- Early survival was high (80% after 4 years) for all seed origins.
- There were no practical differences in form between the seed origins.
- There was a significant linear relationship between growth and latitude indicating that the best seed origins for planting in lowland Britain are in the north of the range of Low's fir.

Forest Research has established 35 experiments that contain Low's fir and one of these, Thetford 72, has confirmed that the species is a good choice for underplanting on a range of sites in Thetford and can tolerate shallow calcareous soils.

In summary, Low's fir is a productive forest tree in lowland Britain and could be used as part of a diversification strategy to reduce the risks of climate change and biotic threats. However, more work is required on the possible effects of the canker *Neonectria*, limiting factors on growth to inform Ecological Site classification and timber properties.

1. Introduction

The correct choice of seed origin is a critical stage in forest management and can result in either a flourishing plantation or a maladapted one with poor growth and form, or even complete failure (Lines 1987). The choice of suitable seed origins will vary for different locations and site types in Britain and needs to consider potential impacts of the future climate as well as current conditions.

Advice on choice of origin can be broadly guided by climate matching between the origin and the planting site taking into account other factors such as seasonal changes in day length and soils. However, such relationships are not always precise because other factors such as isolation, post-glacial migration patterns and competition regulate natural species distributions and there are many examples where the *potential* environmental envelopes are wider than the *realised* ones as indicated by the climates and soils in the natural range.

Ultimately, choice of origins has to be based on information obtained from seed origin and provenance trials and many trials were established in the 20th century for the major and several minor species. There are also species where species trials and limited forest plantings have shown potential for greater use in species diversification but where there are very few trials on which to base advice choice of seed origin.

Low's fir (*Abies concolor* var. *lowiana* (Gord.) Lemm.) is a species in the latter category and this report was commissioned by Stephen Smith, Forest Enterprise England 'to carry out a review of the evidence to produce: (1) preliminary guidelines on the choice of seed origins for Low's fir; (2) indicate potential growth rates compared to a more commonly planted fir species and (3) briefly report on other silvicultural data that may be available in Forest Research'. Parts (1) and (2) are reported in section 2 and part (3) in section 3.

The species range for *Abies concolor* is shown in Figure 1. The needle form and terpene content of the species vary sufficiently across the range of the species to justify the definition of two varieties: the typical *Abies concolor* var. *concolor*, white fir, which occupies the eastern and southwestern part of the range and Low's fir in the western part of the range. Low's fir can be found at sites between 1200 m and 2100 m in the Sierra Neveda and then at lower elevations to the north up to an ill-defined area in the Oregon Cascades. At the northern end of the range it intergrades with *Abies grandis* and at the southern end it merges with the other variety of *Abies concolor*. Specimen trees in Britain have been reported to grow rapidly into large trees and in the late 1960s a series of five experiments were established to further study the growth of Low's fir in southern England. The objectives of this study are:

1. To compare the survival and growth of Low's fir with grand fir[1].

2. To determine the best seed origins for further planting of this species in Britain and examine whether this advice needs to be specific to sites (i.e. is site x seed origin interaction significant).

3. To examine if the results be explained by latitude and/or altitude to help define a wider area from which seed could be collected rather than just one location.

4. To report on other silvicultural data that are available in Forest Research.

2. Seed origin variation in Low's fir

2.1. Experiments

Seed from 19 origins in California and Oregon was made available to the Forestry Commission in 1964 through contact between Alan Mitchell and Mr W.B. Critchfield of the USDA Forest Service, Institute of Forest Genetics in Placeville, California. This seed produced enough planting material for the establishment of five replicated experiments (Alice Holt 180; Brendon 19; Honiton 2; Mortimer 11 and Wareham 149); all were planted in 1968 except Wareham, which was planted in 1966. However, for a variety of reasons only Honiton 2 and Mortimer 11 have survived and produced useful data.

The experiment Honiton 2 was established in Pare Hayne Wood two miles south of Wilmington, Devon (SY224968) at 130 m above sea level. The soil is a very stony, free draining sandy loam on the transition between Upper Greensand and Keuper Marl. All 19 seed origins of Low's fir and a grand fir control (from Vancouver Island) were planted in a randomised block experiment. There were three blocks and each plot was planted with 64 trees at a square spacing of 1.8 m. All plants had been raised in the FC nursery at Wareham and records indicate good establishment practice including fencing and weeding. A small number of trees were beaten-up in February 1969, 13 trees in two blocks and this confirms the recorded information that initial survival was good.

ESC parameters (default mode; no soil information)

AT5 – 1799; CT – 8.1; DAMS 10.8; MD 153 mm; rainfall 1014 mm; SMR Fresh; SNR Medium. Grand fir is rated as 'very suitable' with no real constraining factors (although the most likely is DAMS).

The experiment Mortimer 11 was established in the main block of Mortimer Forest in an area known as Bringewood Chase (SO462735) at 274 m above sea level. Unlike Honiton

[1] The timber of both species has a similar specific gravity (0.37) (Ramsay and Macdonald, 2013; The Wood database (http://www.wood-database.com/lumber-identification/softwoods/white-fir/).

2, this experiment was planted under a sparse overstorey of European larch (40 years old in 1968, density 37 per hectare). The soil is a brown earth and the vegetation was mainly bracken and bramble during the establishment period. Only 18 of the 19 seed origins of Low's fir were planted as there was a plant supply issue with 'Sumpter' and this was replaced by a second grand fir control from Washington State. The experiment was a randomised block experiment with five blocks and each plot was planted with 25 trees at a square spacing of 1.8 m. All plants had been raised in the FC nursery at Wareham and records indicate good establishment practice including fencing and weeding (control of bramble was a serious issue). A small number of trees were beaten-up in February 1969 but this was not formally recorded.

ESC parameters (modified for a brown earth soil)

AT5 – 1316; CT – 9.3; DAMS 10.1; MD 103 mm; rainfall 766 mm; SMR Fresh; SNR Medium. Grand fir is rated as 'marginal' constrained by soil moisture regime.

For each of the seed origins information was available on latitude, altitude and the nearest place name but unfortunately longitude was not available. Therefore it has not been possible to be precise about the exact areas of seed collections for this study and Figure 2 has been drawn using the nearest place names (checked with latitude). In addition, two origins of Low's fir, La Grande and Sumpter, are within the range of grand fir and some further work on species identification is required. Information on the 19 seed origins is given in Table 1.

It should be noted that both experiments had been marked and thinned by the local Forest District at least once before 2015 and an assumption is that this affected each plot in an equal way. Hence some caution is required when interpreting the diameter and form score data.

2.2 Assessments and analyses

2.2.1 Assessments

In Autumn 2015 Honiton 2 and Mortimer 11 were 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').

4. Survival at year 4 was extracted from the experiment files (year 4 data were used to minimize any possible influence of beating-up).

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 a General Yield Class (GYC) has been calculated using the top height-age curves for grand fir in Matthews and Mackie (2006).

The analysis of the data had two parts: (A) to examine the effect of seed origin and site (plus interactions) on height, diameter, early survival and form; (B) to investigate if the results could be explained by latitude, altitude and site.

2.2.2 Effects of seed origin and site

A mixed-effects model was fitted to the data for height, diameter, early survival (transformed to arcsine) and form score. The model included the fixed effects of site, seed origin and the interaction of site and seed origin, including a random block effect, nested within site. Significant factors were determined using type II Analysis of Variance from the R "car" package to take account of the unbalanced design of the data. Where the interaction was not significant, this was dropped from the model. Having determined the best model, post-hoc Tukey's HSD tests were performed to determine significant differences between different seed origins. The same models were applied to the data, excluding grand fir origins, to check the best fit model was the same to ensure the differences were between seed origins and not just between Low's fir and grand fir.

2.2.3 Effects of latitude and altitude

This analysis only used the Low's fir data. A mixed-effects model was fitted to the data, including the fixed effects of altitude, latitude and site, and including block nested within site as a random effect. Significant factors were determined using type II Analysis of variance from the R "car" package adjusts effects for all other main effects included within the model and is appropriate for the unbalanced design of these data. Furthermore, this partitioning of the variance indicates whether the additional variables (altitude and latitude) are significant drivers of height differences in the presence of each other (i.e. indicates whether altitude explains a significant portion of the variance in the data, given the variance explained separately by latitude and *vice versa*). Non-significant factors and variables were dropped from the model.

2.3 Results: seed origin and site

2.3.1 Early survival

- Survival after 4 years was high and generally >80%
- Survival was significantly higher at Mortimer ($P<0.001$)
- Survival was significant between seed origins ($P<0.01$) but this was mainly attributable to one Low's fir seed origin having lower survival than grand fir, so is of little practical relevance (Figure 3).

2.3.2 Height

- Using height after 47 years to estimate yield class showed that Low's fir ranged between GYC 12-28 and grand fir GYC 28-30 (Table 1).
- The effects of seed origin ($P<0.001$) and site ($P<0.05$) were both significant but there was no interaction between these two main effects.
- The analysis has grouped the Low's fir seed origins into three groups compared with grand fir: two are not significantly different (Prineville and Mackenzie Bridge); four are only significantly lower than one of the grand fir controls and 13 are significantly different to both the grand fir controls (Figure 4).

2.3.3 Diameter

- For Low's fir diameter ranged between 31.9 cm for Kyburz and 46.4 cm for Prineville. The two grand fir controls were 48.1 cm (Vancouver Island) and 51.0 cm (Washington).
- Results for the analysis of diameter are similar to those for height but there are more Low's fir seed origins that are not significantly different to grand fir (Figure 5).

2.3.4 Form score

- Trees at Mortimer had significantly higher form scores (mean = 1.83 +/-0.11 (95% CI)) than those at Honiton (mean = 1.46 +/-0.13 (95% CI)) across all seed origins.
- Analysis showed that there were no significant differences, i.e. the grand fir controls are not significantly different to any of the Low's fir seed origins, and that there is no significant difference between the Low's fir seed origins.

2.3.5 Visual summary

- A visual summary of the results in section 2.3 is provided in Table 2.

2.4 Results: latitude and altitude

2.4.1 Early survival

- There were no significant effects of latitude or altitude on early survival.

2.4.2 Height

- There were significant effects of latitude ($P<0.001$) and site ($P<0.05$) on height but no significant interaction.

- The model shows there was an increase in height of 1.19 m per 1 degree increase in latitude (i.e. travelling north); this is equivalent to a 9.03 metre difference across the latitudinal range (Figure 6).
- The analysis confirmed the dominance of latitude over altitude; this is important as the two factors are highly correlated.

2.4.3 Diameter

- There was only a significant effect of latitude ($P<0.001$).
- The model shows there was an increase in DBH of 1.65 cm per 1 degree increase in latitude (i.e. travelling north); this is equivalent to a 12.5 cm difference across the latitudinal range (Figure 7).

2.4.4 Form score

- There were significant effects of latitude ($P<0.01$) and site ($P<0.01$) on form score but no significant interaction.
- The model shows there was a decrease in form score of 0.033 per 1 degree increase in latitude (i.e. travelling north); this is equivalent to a 0.25 difference across the latitudinal range. This result has no practical relevance.

2.5 Conclusions

1. Low's fir was a productive forest tree and achieved up to GYC28 with good form on the two sites described in this study. It can probably be planted on a range of lowland sites but the main limiting factors to growth in Britain would need to be determined by further work.
2. With good choice of seed origin Low's fir can be as productive as grand fir, the species it merges with in the northern part of its native range.
3. The best area for future seed collections for the use of Low's fir in southern Britain are from the northern part of its range. Seed origins from further south can still be productive and could play a part in the diversification of forests in Britain in response to climate changes and biotic threats but there would be a productivity penalty.
4. Further work on the limiting factors on the growth of *Abies concolor* is required so it can be included as a species option in Ecological Site classification. One factor that could be important in the future is the canker *Neonectria* (see https://gd.eppo.int/reporting/article-2696). In addition, more work to confirm its timber properties would be also be justified to confirm Laacke's (1990) description of it as a 'general, all-purpose, construction grade wood used extensively for solid wood construction framing and plywood'.

3. Other FR data on Low's fir

The objective of this part of the study was to characterize other Forest Research data on Low's fir that may be available for further work and to answer a specific question from East England Forest District about the experiment Thetford 72.

A search of the Silviculture Experiment Database located 35 experiments that contained Low's fir, of these 9 are open experiments of which 8 are designated as having long-term strategic value. The experiments are widely distributed in forests throughout Britain and historic data may exist for them or new assessments could be collected if they still exist on the ground. One potential problem could be the coding of the different types of *Abies concolor* when information was entered on to the database. This means that it is not 100% certain that the species is Low's fir, it may just contain *Abies concolor*.

The experiment Thetford 72 was established in 1964 to examine a range of alternative species to Corsican pine in terms of establishment success, yield and resistance to Annosum root rot (*Heterobasidion annosum* (Fr.) Bref). A randomised block experiment of 18 alternative species was established at three sites, each of which had a different soil type and therefore risk of being infected. The three soils were chosen to be typical for Thetford forest are were:

Site A - Deep acid sandy soil (<75 cm, pH 4.5) [Worlington series]

Site B – Brown calcareous soil (30-60 cm deep, pH 6.0) [Methwold/Worlington series]

Site C – Shallow calcareous soil (<30 cm deep, pH 8.0) [Newmarket series]

All three experiments were planted under a 30-40 year-old canopy of Scots pine, which was deemed necessary to provide protection for the more frost tender species and increases their value in terms of contemporary silviculture of Corsican pine in Thetford.

An assessment of yield class at age 15 has been published in Greig (2003) and is reproduced as Table 3. In addition, the 5 year growth data has also been analyzed using analysis of variance and this is presented as Table 4.

The data In Table 3 and 4 confirm that Low's fir is one of the best *Abies* species to plant on a range of sites in Thetford and could tolerate, at a reduced rate of growth, the shallow calcareous soil. In addition, data in Gibbs *et al*. (2002) confirm that Low's fir only suffers a 'low level of killing' in the presence of Annosum root rot.

Table 1. Summary of seed origins used in experiments and provisional information on location of collections

Species LF/GF	Seed origin	Lat. (°N)	Altitude (m)	Site [Mean height and (GYC)]	
				Honiton	Mortimer
LF*	La Grande	45.28	1341	31.8 (24)	33.3 (26)
LF*	Sumpter	44.78	1524	31.1 (24)	n/a
LF	Prineville	44.50	1219	32.6 (24)	35.4 (26)
LF	McKenzie Bridge	44.30	1219	33.7 (26)	35.6 (28)
LF	Crescent1	43.00	1372	31.1 (24)	33.3 (26)
LF	Crescent2	43.00	1676	33.0 (26)	34.1 (26)
LF	Fort Klamath	42.78	1372	32.0 (24)	34.8 (28)
LF	Bly1	42.48	2134	29.9 (22)	25.3 (16)
LF	Bly2	42.35	1524	29.5 (22)	31.8 (24)
LF	Cave Junction	42.02	1585	29.2 (20)	30.6 (22)
LF	Cedarville	41.50	1829	26.2 (16)	25.6 (16)
LF	Tulelake	41.47	1646	30.4 (22)	28.9 (20)
LF	Salyer	40.75	1798	29.1 (20)	33.6 (26)
LF	Oakrun	40.70	1463	28.6 (20)	22.0 (12)
LF	Westwood	40.42	1981	26.3 (16)	24.2 (14)
LF	Meadow valley	39.90	1737	29.1 (20)	23.3 (14)
LF	Stoneyford	39.48	1890	26.6 (18)	27.2 (18)
LF	Kyburz	38.90	1676	24.5 (16)	21.2 (12)
LF	Mammoth Lakes	37.73	2316	26.5 (18)	23.6 (14)
GF	Vancouver Island	49.00	n/a	37.2 (30)	37.8 (30)
GF	Washington	44.00	n/a	n/a	36.6 (28)

* These origins fall within the species range of grand fir, see Figure 2.

Table 2. Overview of Low's fir seed origin data, comparing different growth and survival aspects with two origins of grand fir

Provenance	Height	DBH	Early Survival	Form Score
McKenzie Bridge	= =	= =	= =	= =
Prineville	= =	= =	= =	= =
Crescent1	= <	= =	= =	= =
Crescent2	= <	= =	= =	= =
Fort Klamath	= <	= =	= =	= =
La Grande	= <	= =	= =	= =
Meadow valley	< <	= =	= =	= =
Salyer	< <	= =	= =	= =
Bly2	< <	= <	= =	= =
Cave Junction	< <	= <	= =	= =
Sumpter	< <	= <	= =	= =
Tulelake	< <	= <	= =	= =
Westwood	< <	= <	= =	= =
Bly1	< <	< <	= =	= =
Cedarville	< <	< <	= =	= =
Kyburz	< <	< <	= =	= =
Oakrun	< <	< <	= =	= =
Stoneyford	< <	< <	= =	= =
Mammoth Lakes	< <	< <	= <	= =

Colour-coding and symbols based on statistical analysis, making pairwise comparisons ($p<0.05$) with two grand fir seed origins for each growth measure (green = = : Low's fir origin not significantly different from either Grand fir seed origin; amber = < : Low's fir seed origin not significantly different from one grand fir seed origin but less than the other; red < < : Low's fir seed origin growth measure significantly less than both grand fir origins.

Table 3. GYC assessment of Thetford 72 reproduced from Greig (2003)

Species	Soil type/GYC		
	Soil A	**Soil B**	**Soil C**
Western hemlock	14	6	6*
Leyland cypress	14	18*	12
Douglas-fir	12	10	6
Omorika spruce	10	10	10
Scots pine	8	8	8
Corsican pine	8	8	6
Hybrid larch	8	8*	4
Low's fir	8	8*	4
Lawson cypress	8	12	8
Western red cedar	6	10*	6
Grand fir	6	6	4
Red oak	6	6	Failed
Nothofagus obliqua	6	4	4
Abies alba	4	4	4
Beech	4	6	6
Abies cephalonica	Survival was <50%		
Abies amabilis	Species failed		
Atlantic cedar	Species failed		

* values rounded up from odd numbers in original table.

Table 4. Analysis of 5 year height data for Thetford 72

Species	Soil type/Mean height (cm)		
	Soil A	Soil B	Soil C
Western hemlock	200	128	59
Leyland cypress	142	212	163
Douglas-fir	149	124	106
Omorika spruce	100	90	81
Scots pine	98	109	96
Corsican pine	83	66	50
Hybrid larch	168	160	98
Low's fir	70	54	36
Lawson cypress	115	148	106
Western red cedar	152	101	68
Grand fir	69	59	36
Red oak	153	96	45
Nothofagus obliqua	357	203	125
Abies alba	63	36	37
Beech	89	108	86
Abies cephalonica	25	20	28
Abies amabilis	47	30	23
Atlantic cedar	Failed		
Site; Species and Site × Species all statistically significant at P<0.001 SED – Site (32); Species (77); Site × Species (133)			

Figure 1: The species range of *Abies concolor* and *A. grandis*

[Species ranges are modified from USGS (1999)]

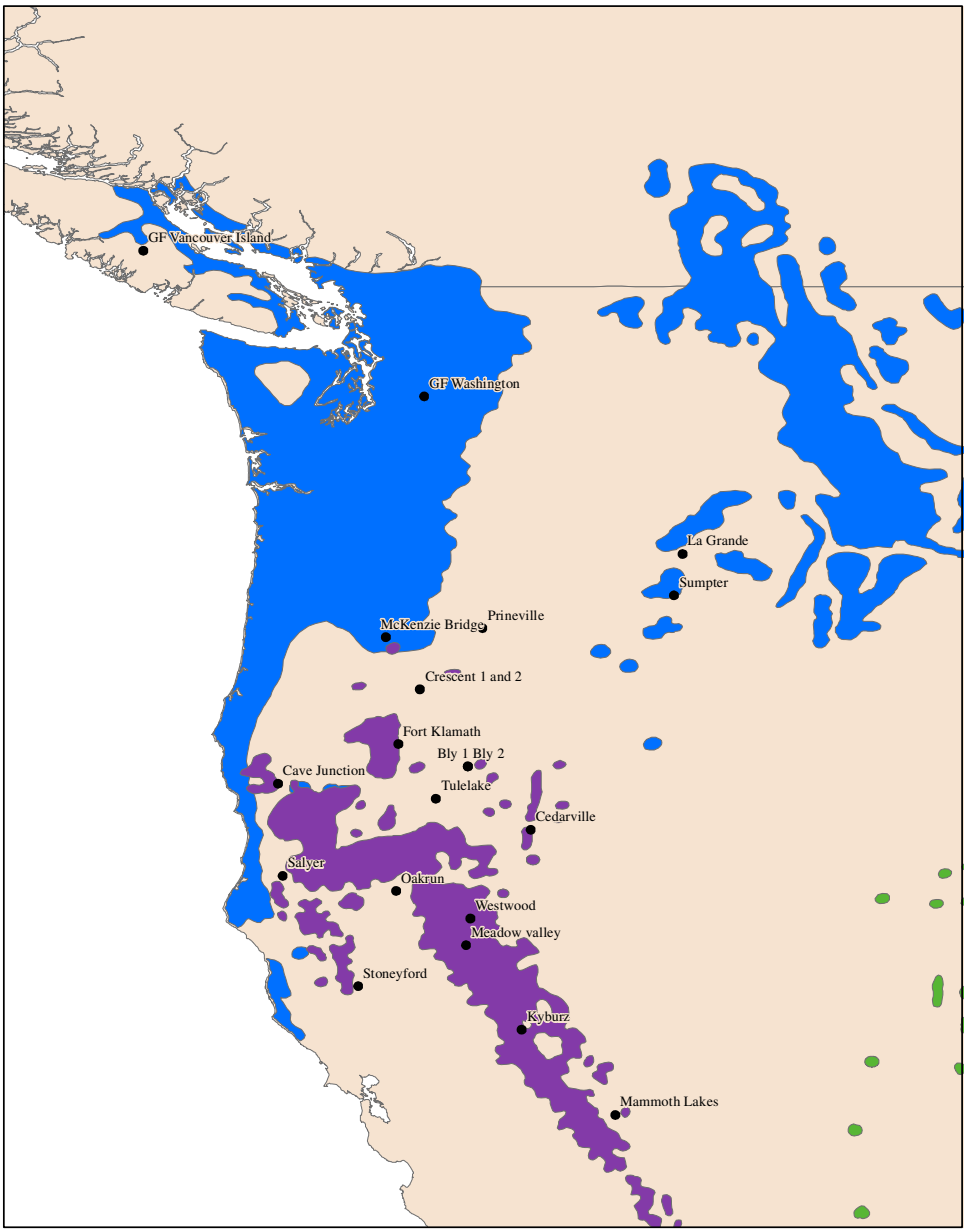

Figure 2: Map showing the place names of the seed origins examined in this study (only latitude, altitude and nearest place name were recorded so it's difficult to be precise about the exact location where seed was collected).

[Species ranges are modified from USGS (1999)]

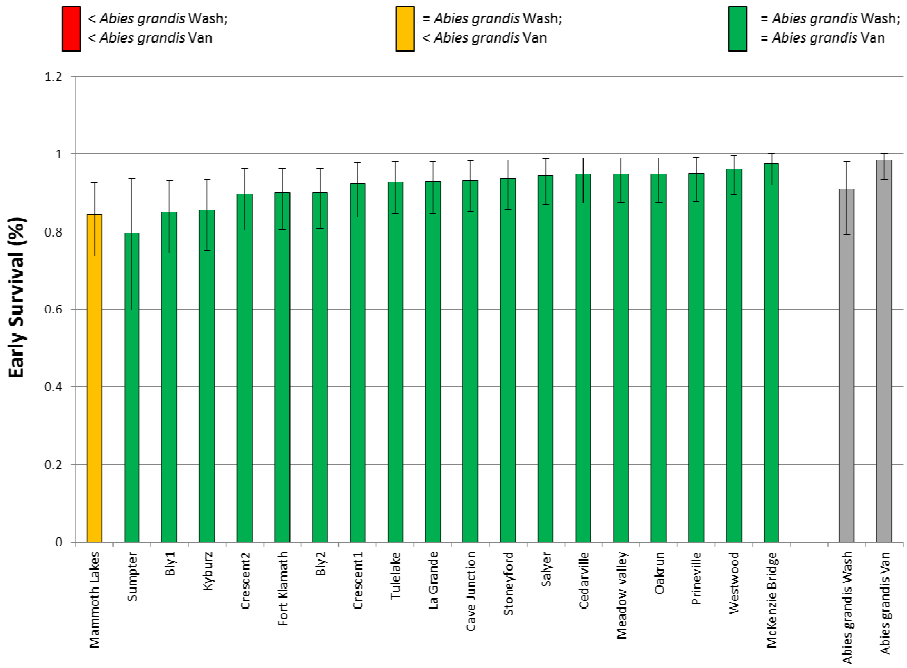

Figure 3: Early survival of Low's fir seed origins (amber, green) and grand fir (grey). Signs ("="; "<") refer to statistically significant differences; error bars = 95% confidence intervals.

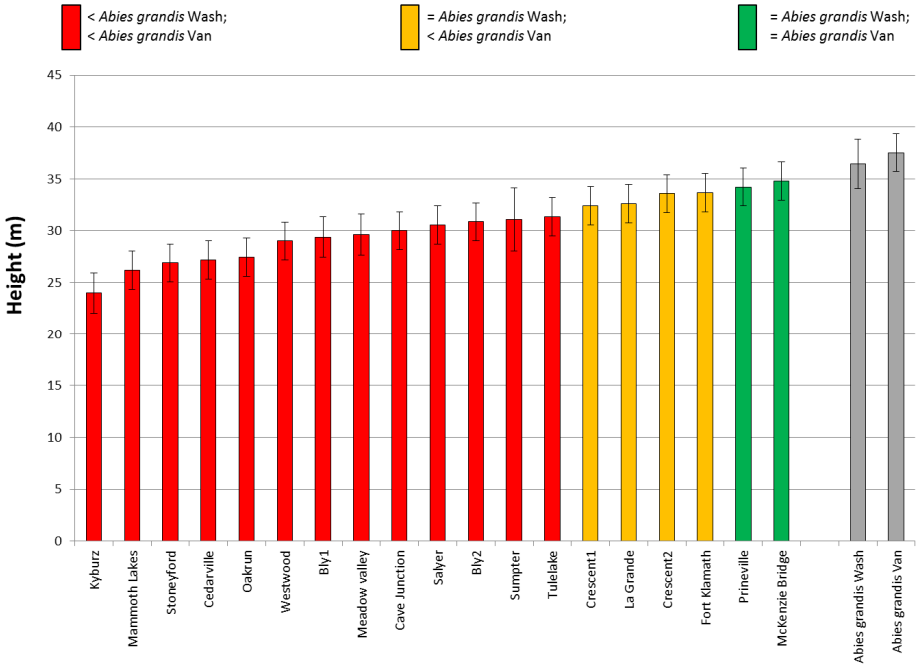

Figure 4: Estimated top height of Low's fir seed origins (red, amber, green) and grand fir (grey). Signs ("="; "<") refer to statistically significant differences; error bars = 95% confidence intervals.

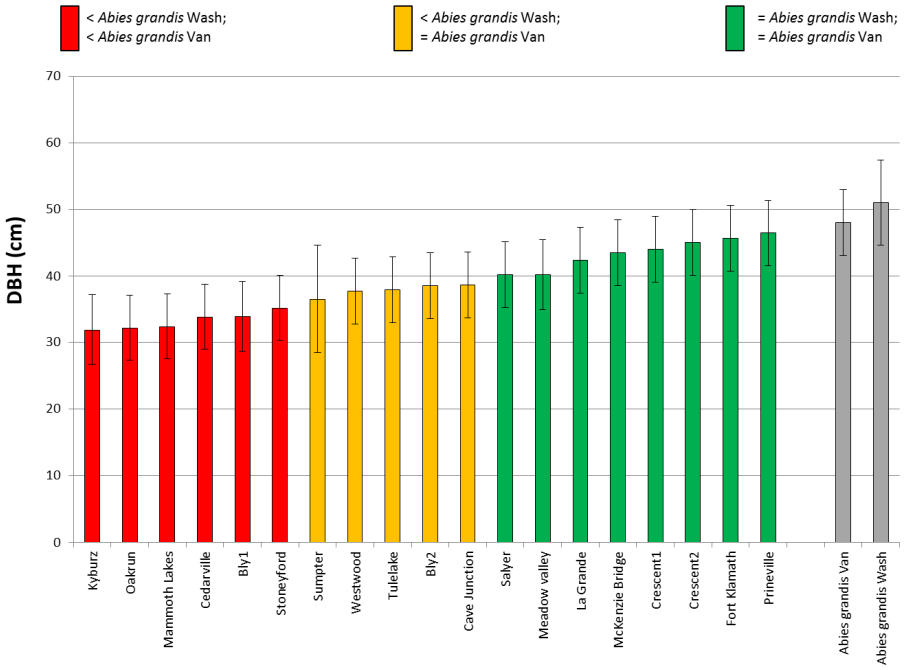

Figure 5: Mean DBH of Low's fir seed origins (red, amber, green) and grand fir (grey). Signs ("="; "<") refer to statistically significant differences; error bars = 95% confidence intervals.

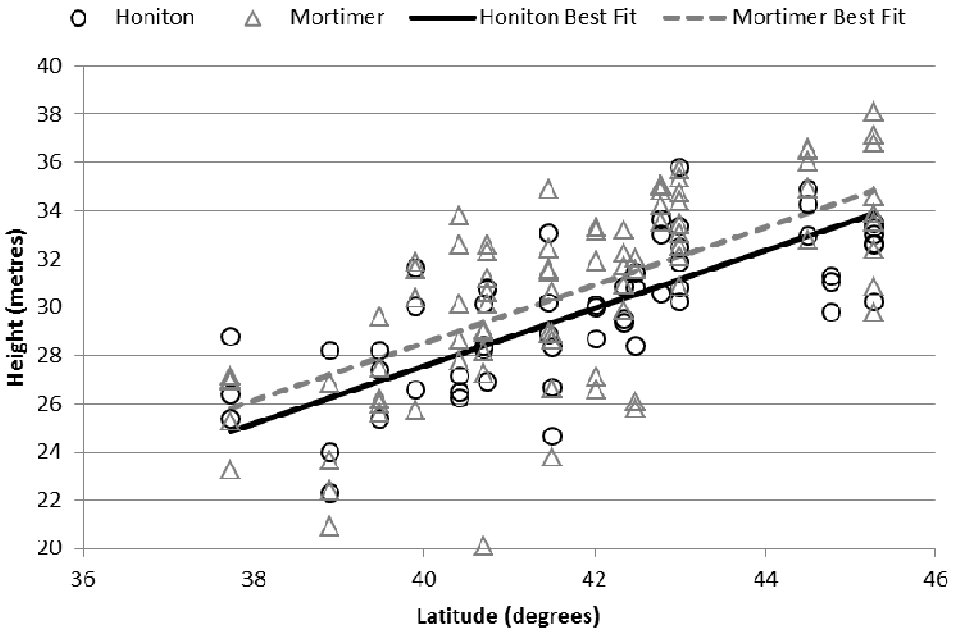

Figure 6: Best fit model applied to Low's fir height data

[(Honiton height = -20.29+1.19*Latitude; Mortimer height = -19.31+1.19*Latitude)]

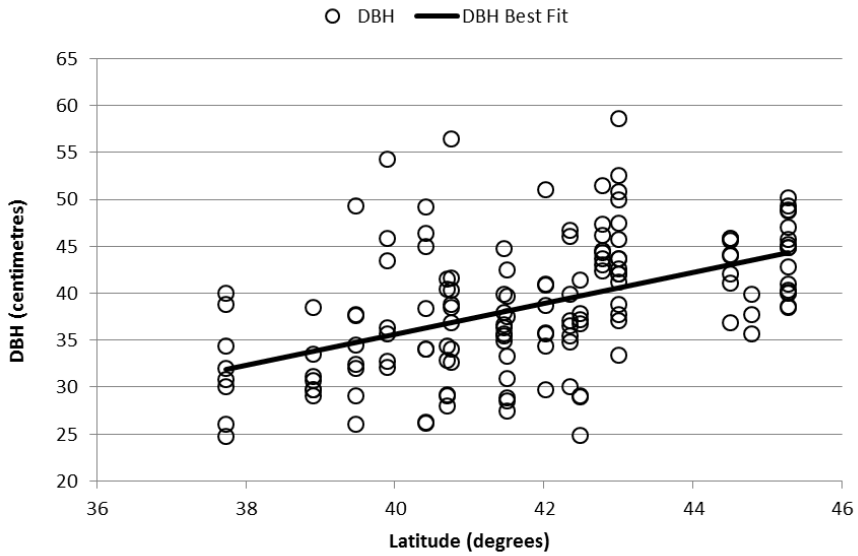

Figure 7: Best fit model applied to Low's fir DBH data
[(DBH = -30.55+1.65*Latitude)]

4. References and acknowledgements

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