Forest Research

Summary of FR Seed Origin Trials on *Cryptomeria japonica* and *Sequoia sempervirens*

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The Research Agency of the Forestry Commission

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Front cover pictures: (left) *Cryptomeria japonica* at the Kilmun Forest Garden, Argyll; (right) *Sequoia sempervirens* at the Royal Forestry Society's Redwood Grove at Leighton, Montgomeryshire in Wales.

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Executive summary

There is growing interest in Japanese red cedar and coast redwood in British forestry because both species are actively being considered as a means of diversifying commercial forests. However, information on how survival and growth of the two species varies with seed origin is scarce and the two species are not included in Forestry Commission Bulletin 66 'Choice of seed origins for the main forest species in Britain' (Lines, 1987).

This report was commissioned by John Weir, Forest Services England, for Forest Research 'to carry out a rapid review of the evidence to produce preliminary guidelines on the choice of seed origins for *Cryptomeria japonica* and *Sequoia sempervirens*'.

The evidence base for the review was limited. For Japanese red cedar there was one replicated experiment in Cornwall and a series of demonstration plots in Scotland, both were planted in 1958 and between them included 11 seed origins. For coast redwood there were two replicated experiments and two sets of demonstration plots planted between 1965 and 1968, including material from two collections focussed on the northern, central and southern part of the native range.

Analysis and interpretation of the data for both species has been heavily compromised by the lack of precise information on the locations of the seed collections. For Japanese red cedar there were significant relationships between survival and latitude as well as height and latitude. Based on this provisional guidance is that seed origins from mid-latitudes of Honshu (34°N to 38°N) are probably best suited to use in Britain. In addition, the potential productivity of the species was confirmed: at the Scottish site the volume productivity was estimated to be GYC20. The integrity of the data for coast redwood was better and showed that: (1) the species is resilient to a range of establishment problems because of its ability to reshoot and coppice, and (2) southerly origins from south of the San Francisco Bay area should be avoided for use in Britain.

This rapid review has identified important knowledge gaps that need to be addressed as part of future research on emerging species for British forestry.

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.

Japanese red cedar (*Cryptomeria japonica* (Thunb. ex L.f.) D.Don) and coast redwood (*Sequoia sempervirens* (D.Don) Endl.) are species in the latter category and this report was commissioned by John Weir, Forest Services England 'to carry out a rapid review of the evidence to produce preliminary guidelines on the choice of seed origins for *Cryptomeria japonica* and *Sequoia sempervirens*'.

Japanese red cedar and coast redwood can also be propagated vegetatively using shoot cuttings but clonal testing in Britain has been limited to demonstrating the feasibility of the propagation technique and has not been taken further to select and test clones with superior traits.

2. Provenance variation in Japanese red cedar (*Cryptomeria japonica* (Thunb. ex L.f.) Don.)

2.1. Experiments

Seed from nine origins in Japan was made available to the Forestry Commission in the mid-1950s through contact with a 'Dr. Lindquist and Professor Asakawa'. This seed produced enough planting material for the establishment of one replicated experiment (Glynn 4 in Cornwall) and a series of demonstration plots in Scotland (Loch Goil 1), both were planted in 1958. The objective of the experiments was 'to test the hypothesis that there is no difference in the survival, height growth, form, phenological character or resistance to frost, insects or disease between any of the provenances'. The opportunity was also taken to include two other treatments; the first was seed from a tree in Kilmun Forest Garden, Argyll and the other was cuttings available from the Royal Botanic Garden in Edinburgh (Table 1). The experiment Glynn 4 was established in the bottom of a small valley just south of the main A38 at SX143648 at 100m above sea level. There is no information in the file on the soil type but the site was rated 'good' and is probably a brown earth. There was two parts to the experiment: small intensive plots with 10 treatments and larger extensive plots with 6 seed origins. The intensive plots were planted on the western side of the valley (aspect east) and the extensive plots were planted on the eastern side (aspect west). Comments in the experiment file suggest the site of the intensive plots was better partly due to shelter. The intensive plots each had nine trees (spacing 1.8 m x 1.8 m) and there were three replicates. The extensive plots had 81 trees (spacing 1.8 m x 1.8 m) and there were four replicates in a Latin square with an 'added plot' of 56/227. Records indicate that the whole experiment was beaten-up in 1959 and provenance 55/114 was planted a year late; in addition, there were two applications of triple superphosphate in 1962 and 1965.

ESC parameters (default mode; no soil information)

AT5 – 1857; CT – 7.3; DAMS 17.6; MD 135 mm; rainfall 1283 mm; SMR Fresh; SNR Poor. Japanese red cedar 'unsuitable' constrained by DAMS.

The trial Loch Goil 1 was established on an upland brown earth soil at NN194016 at 20 m above sea level. Each of the six plots had 30 trees (spacing 1.5 m x 1.5 m). Unfortunately the plots were lost to a chalet development some time after 1983.

ESC parameters (default mode; no soil information)

AT5 – 1438; CT – 4.4; DAMS 9.5; MD 129 mm; rainfall 2653 mm; SMR Very Moist; SNR Very Poor. Japanese red cedar 'unsuitable' constrained by SNR.

The main weakness of the experiments is the absence of accurate information on the original location of the seed collections. There are also discrepancies between the information in the experiment plan and Forestry Commission (1965). The latitudes and longitudes in Table 1 were determined using Google maps; where the prefecture was the best location the mid-point of this was taken (Figure 1). No information on altitude was available.

2.2. Assessments and analysis

The intensive plots at Glynn 4 were assessed for survival and height growth annually until 1965; assessment of the extensive plots stopped in 1961. Loch Goil was assessed five times until 1983. Summary data for survival and height were plotted for initial examination (Figures 2-5); in each Figure the most southerly origin is on the left and the most northerly on the right.

The height data for the intensive plots at Glynn 4 have been analyzed using analysis of variance; the April 1964 data were used as the later assessment was only available as summary information. Survival data were analyzed using a generalized linear model with a binomial distribution and a logit link function; the model was constant+blocks+seed origin.

Investigating relationships between survival and height and geographic location is complicated because the main axis of Honshu runs roughly south west to north east and so the latitudes and longitudes of the seed origins are highly correlated (r=0.98) so that the most southerly point is also the most westerly, and the most northerly is the most easterly. Consequently, only latitude was used as a measure of location and quadratic regressions were carried out between the survival and height of the provenances at Glynn 4 (intensive plots) and the provisional latitude specified in Table 1.

The data from Loch Goil were not analyzed as there was only a single replicate. However, the data were ranked along with that from intensive and extensive plots at Glynn 4 to get an overview of how different provenances had performed in the study; for this the 1964 data were used from the intensive plots, 1961 data from the extensive plots and 1968 from Loch Goil. Kendall's coefficient of concordance was calculated for survival and height for seed origins represented in all three sets of data.

The mean height of the plots at Loch Goil in 1983 was used as an estimate of top height to give an indicative general yield class using the top height – age relationships for western red cedar.

2.3. Results

2.3.1. Survival

Analysis of the results for the intensive plots at Glynn 4 shows that there were significant differences between the seed origins (Table 2). The April 1964 data were selected for analysis to minimize the effects of beating-up, the effects of which can be seen for provenances 55/114, 55/116 and 55/119 between 1958 and 1960 (Figure 4). In general survival was good: at Glynn 4 (intensive) 8 of the seed origins were >80% in April 1964 and at Loch Goil 4 of the 7 treatments were >80% in 1968 (Figure 4). Comments from the experiment files indicate that this was the result of quite intensive silviculture including the application of fertilizer and there are frequent notes of poor growth and damage that are difficult to take into account.

2.3.2. Height

Analysis of the results for the intensive plots at Glynn 4 shows that there were significant differences between the seed origins (Table 2). These differences can be clearly seen in Figure 5 and the 1964 and 1965 data indicates seven seed origins with good height growth and three that are relatively slow. At Loch Goil, where height growth was much better than at Glynn, there was less variation between provenances and the estimated top height in 1983 was 15.6 m, which suggests GYC20.

Analysis of the ranking for survival and height between the three sets of data indicated there was some degree of agreement but this was not strong (Table 3).

2.4. Geographic location

Analysis of the relationships with latitude showed that there was a small but significant ($P<0.05$) quadratic effect for survival and height (Figure 6). For survival values were lower for the most southerly seed origin (55/106) which is from an island just below Honshu. For height the values were lower for the most southerly and northerly seed origins and this effect can also be seen more generally in the height data from Glynn if the cuttings (56/227) are ignored (Figure 5).

This analysis was heavily compromised by the approximate locations available and the lack of data on altitude; the latter is likely to be a key factor because of the mountainous topography of Japan.

2.5. Conclusions

1. A visit to Glynn 4 in 2008 described it as an 'impressive stand' and the data from Loch Goil indicates high productivity, i.e. GYC20. This shows that that the species deserves more serious study as part of the diversification strategy for British forestry.

2. There were differences between the eleven provenances that were tested in the experiments and a significant quadratic effect was determined for survival and height. This indicates that seed origins from mid-latitudes of Honshu (34°N to 38°N) are probably best suited to use in Britain based on the limited information available. However, further studies are required to refine this guidance and take account of the influence of altitude.

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

Origin ID	Region or National Forest(NF)/Prefecture	Lat. (°N)	Long. (°E)	Sites		
				Glynn intensive	Glynn extensive	Loch Goil
55/106	Yakushima	30.36	130.51	X		
55/108	Kawaharada, Miyazaki	31.85	131.14	X		
55/114	Shizukuishi, Iwate	39.7	140.98	X	X	X
55/115	Takata NF, Niigata	37.78	139.14	X		X
55/116	Yanase NF, Kooti	35.3	134.87	X	X	X
55/117	Tottori NF, Tottori	35.37	134.13	X		
55/118	Sibata NF, Niigata	37.94	139.32	X	X	
55/119	Nanakura NF, Akita	39.7	140.24	X	X	X
55/120	Sirasawa NF, Akita	39.7	140.24	X	X	X
53/210	Benmore Forest Garden*	36.71	140.57			X
56/227	*Cryptomeria fortunei*, Central plain of China**	N/A	N/A	X	X (single plot)	X

* Ex ID 31/20 Takahagi near Tokyo 1 Baraki, Japan

** Plants from cuttings ex RBG Edinburgh

Table 2. Analysis of Glynn 4 (intensive plots) – 1964 data

Origin ID	Region or National Forest(NF)/Prefecture	Survival (%)	Height (cm)
55/106	Yakushima	62.9	0.73
55/108	Kawaharada, Miyazaki	96.2	1.04
55/114	Shizukuishi, Iwate	80.0	0.86
55/115	Takata NF, Niigata	100.0	1.29
55/116	Yanase NF, Kooti	92.5	1.23
55/117	Tottori NF, Tottori	92.5	0.83
55/118	Sibata NF, Niigata	100.0	1.23
55/119	Nanakura NF, Akita	96.2	0.97
55/120	Sirasawa NF, Akita	80.0	0.67
53/210	Benmore Forest Garden		
56/227	*Cryptomeria fortunei*, Central plain of China	74.0	1.54
Mean (SED)		89.3	1.04 (0.21)
Probability		0.025	0.009

Table 3. Rankings of survival and height for the three sources of data

Origin ID	Glynn 4 intensive		Glynn 4 extensive		Loch Goil 1	
	survival	height	survival	height	survival	height
55/106	[red]	[red]				
55/108	[green]	[orange]				
55/114	[orange]	[orange]	[red]	[red]	[orange]	[red]
55/115	[green]	[green]			[green]	[green]
55/116	[orange]	[green]	[red]	[green]	[red]	[orange]
55/117	[orange]	[red]				
55/118	[green]	[green]	[green]	[green]		
55/119	[green]	[orange]	[green]	[orange]	[green]	[orange]
55/120	[orange]	[red]	[orange]	[red]	[orange]	[red]
53/210					[orange]	[orange]
56/227	[red]	[green]	[orange]	[orange]	[red]	[green]
Key:	[green]	Top rank				
	[orange]	Middle rank				
	[red]	Bottom rank				

Kendall’s coefficient of concordance was 0.533 for survival and 0.511 for height (5 common origins for both tests) [0=no agreement between ranks;1=full agreement between ranks]

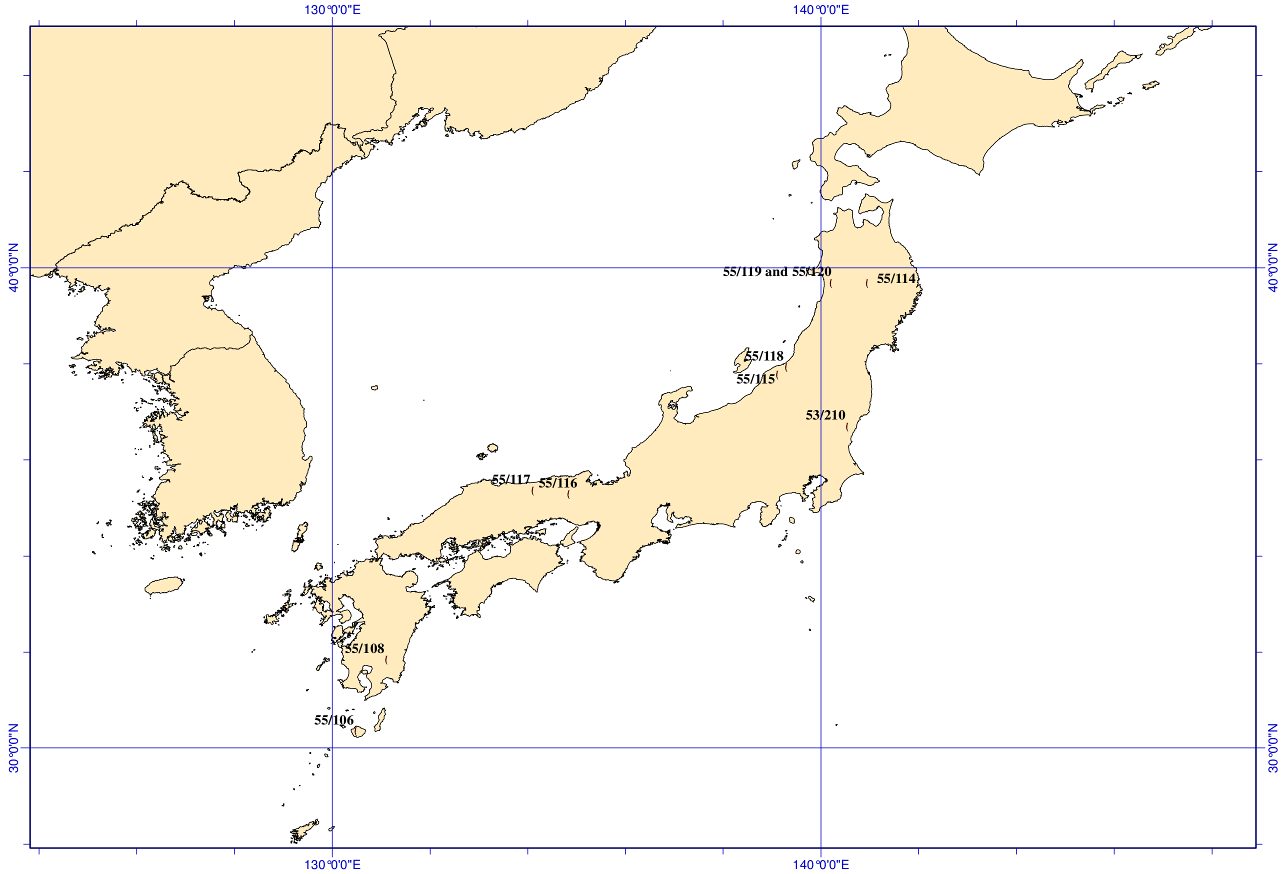

Figure 1. Approximate locations of seed origins of *Cryptomeria japonica*.

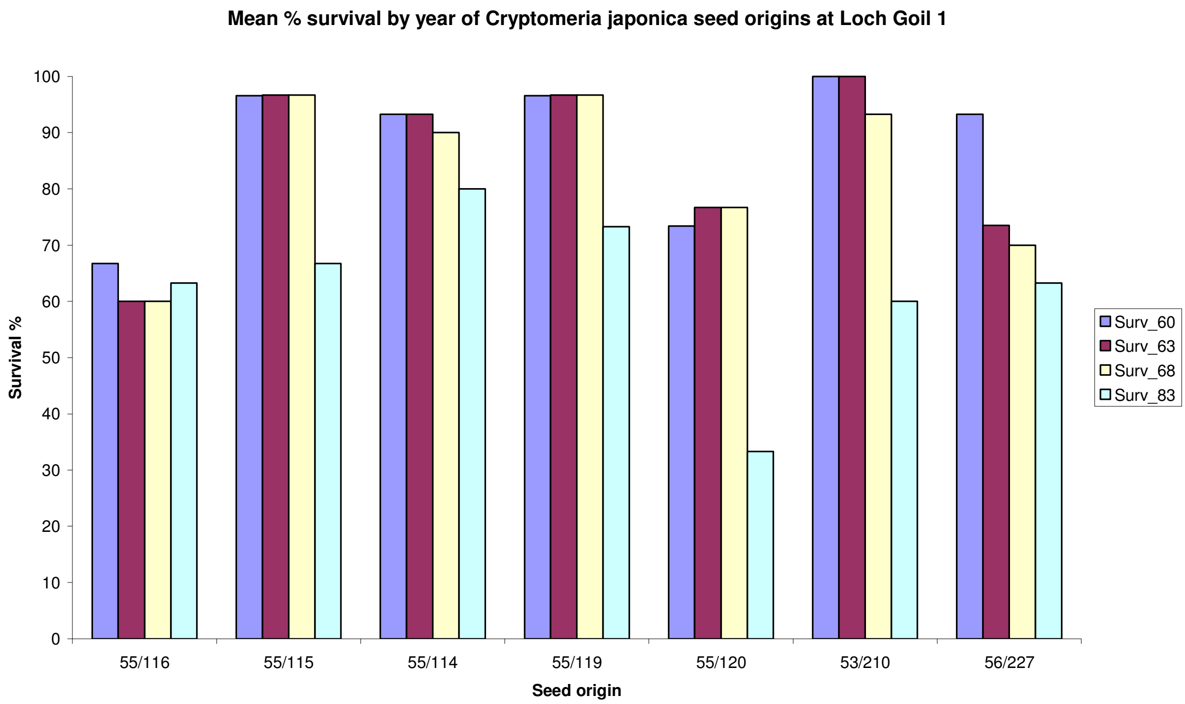

Figure 2. Survival at Loch Goil 1.

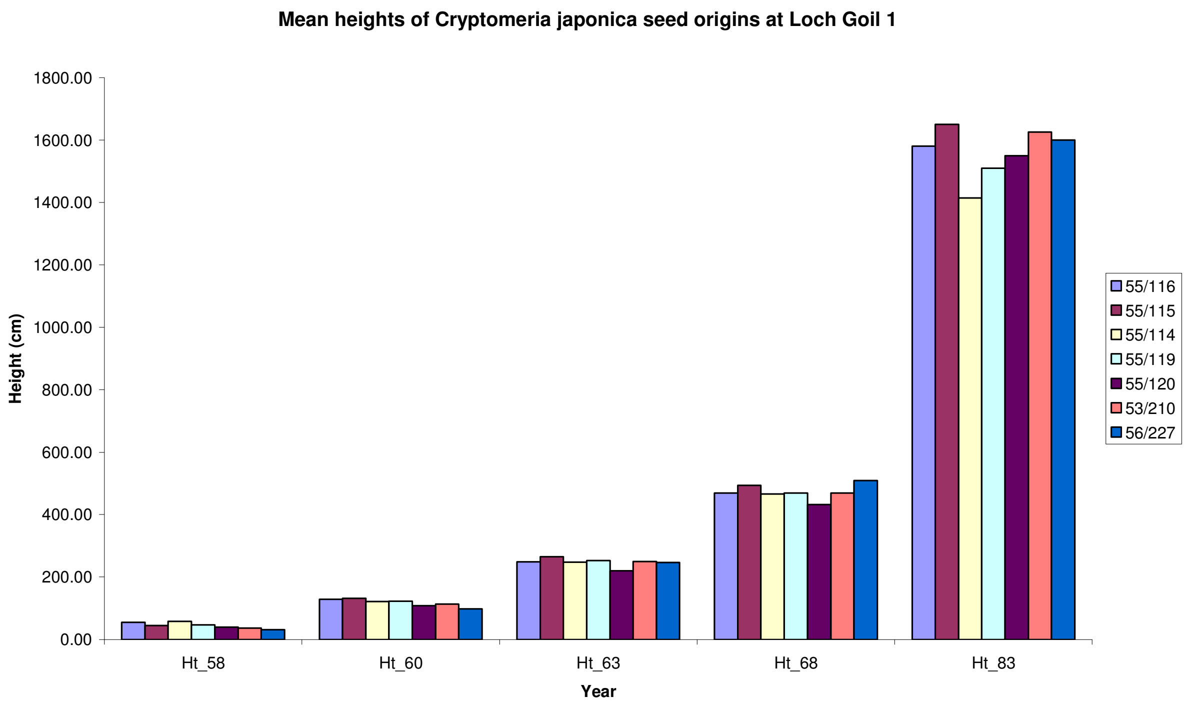

Figure 3. Height at Loch Goil 1

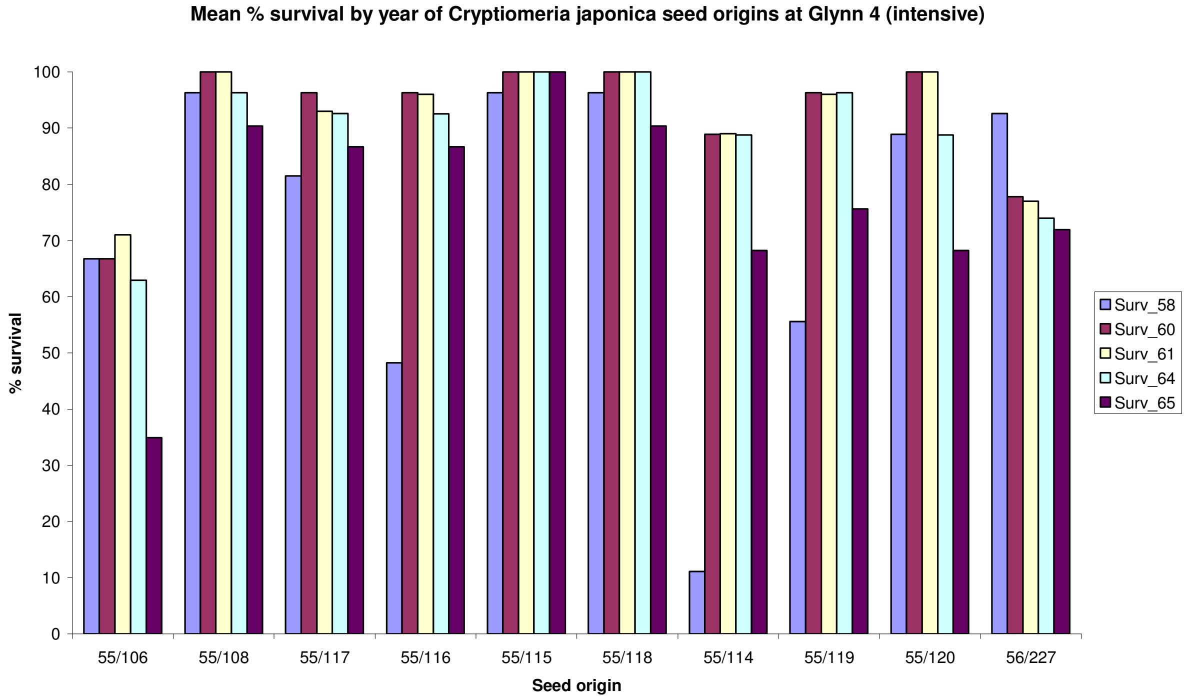

Figure 4. Survival at Glynn 4 (intensive plots)

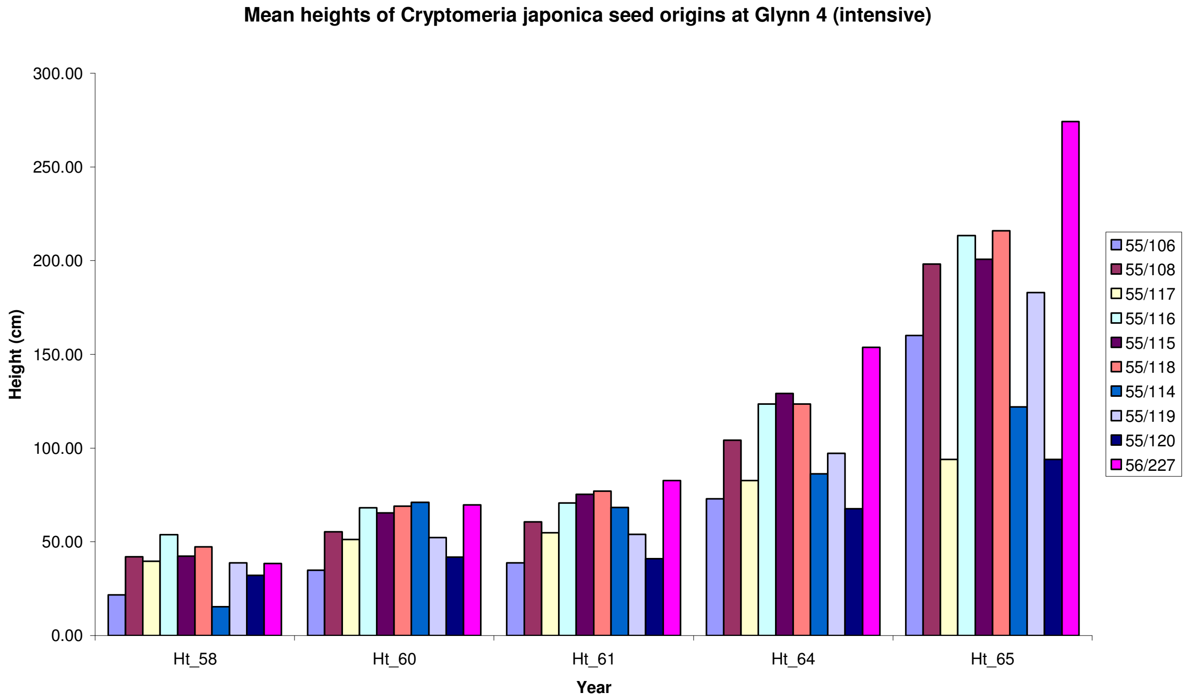

Figure 5. Height development at Glynn 4 (intensive plots)

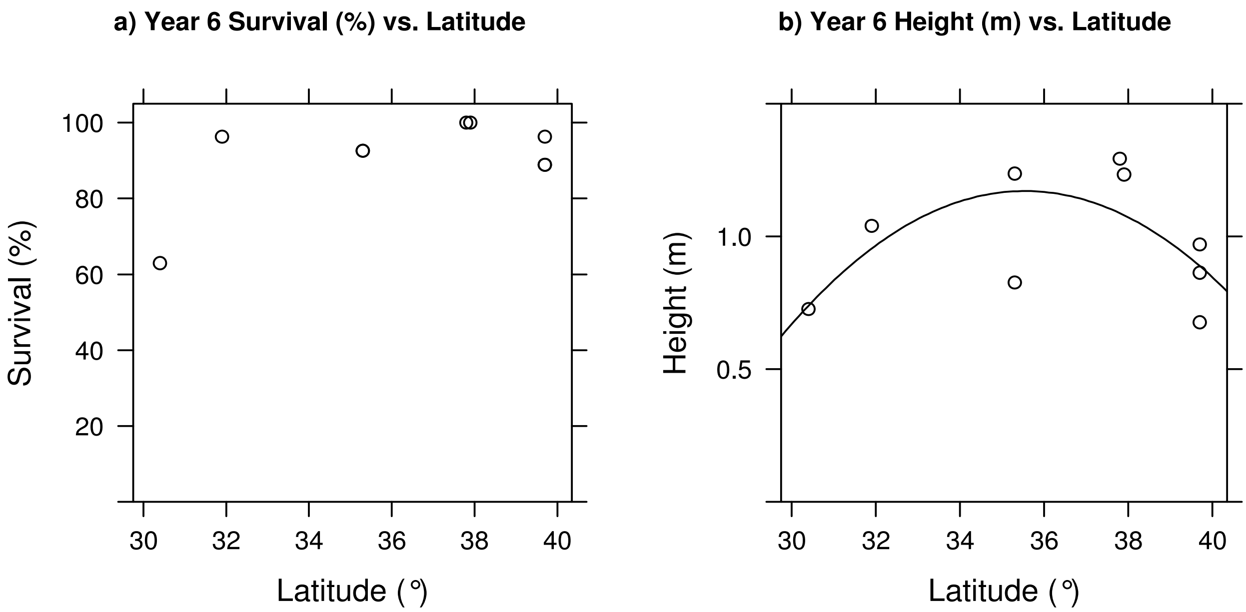

Figure 6. Relationships between survival and height with latitude in Glynn 4.

3. Provenance variation in coast redwood (*Sequoia sempervirens* (D. Don) Endl.)

3.1. *Sequoia sempervirens* seed origin trials

Coast redwood grows in a relatively narrow strip of land along the coast of southern Oregon and California (Figure 7). This area has high rainfall (2500 mm annually) and is cool with high humidity and frequent fogs. Coast redwood is a valuable timber species in the USA and has been planted for forestry in other regions such as New Zealand. It was first introduced into Britain in 1843 and has been trialled on a limited scale as a forest species for timber production.

In 1962 and 1963 seed samples from a range-wide collection were sent by the University of California to Alice Holt Research Station for use in seed origin trials.

The collections were made from along the latitudinal range of the natural distribution (Figure 7) although the focus seems to have been on the most northern, southern and middle parts of the range.

The exact origins of the seed lots are imprecise because they were identified by place names that appear to refer to either the nearest town or other point-feature close to the collection area, or to a wider region such as a river basin. Grid references for the collecting sites were apparently obtained from a road map of California (Figure 7).

Within each collecting location, individual seed collections were made from between one and three trees (Table 4). Each place x tree-number combination is referred to here as a 'seed origin' and is labelled by Place Name and allocated tree code number, e.g. Brookings 1001.

Overall seed quality, as determined by germination tests, was poor with germination capacities below 10%, except for two origins which achieved nearly 25% germination.

Sufficient seedlings were raised at Alice Holt for establishing in 1965 a replicated trial in Devon (Plym 3) containing 11 seed origins (See Tables 4-6 for details of seed origins, experimental designs, and site factors for each experiment). Spare seedlings of these origins, together with additional origins with insufficient seedlings for a trial, were planted out as single replicate demonstration plots at Plym 3 and at Alice Holt (experiment Alice Holt 147).

In 1968, a second replicated trial was planted at Weston Common in Hampshire (Alton 24) using some seed origins from the previous trail and additional ones apparently received in 1963.

3.2. Assessments and analyses

Measurements of these experiments were made over the first seven years after planting so only early growth and survival can be analysed using available records.

Plym 3 was set up as replicated experiment in three blocks and the significance of differences between seed origins in survival and mean height for each plot at age 7 years were analysed by generalised linear models (GLM, binomial errors and logit link with Block as a random factor) and analysis of variance (ANOVA) respectively. Linear models were also used to test for any statistical relationships with latitude (survival, GLM with binomial errors and logit link; height, quadratic regression).

No data were found for the single replicate demonstration plots at Plym.

Mean survival and height at Year 7 for the single replicate demonstration plots in Alice Holt 147 are presented in Figure 9, and relationships with latitude were tested using fitted linear models.

Unfortunately individual plot data on survival and growth in Alton 17 are not available so precluding a full statistical analysis. Only summaries of height after Year 6 and survival after two years were available and these were analysed as for Alice Holt 147.

3.3. Results

All three experiments suffered from frost damage, weed completion and herbivore damage during establishment. However, coast redwood appears to have good recovery from browsing and frost dieback and this probably relates to its ability to produce coppice shoots.

It must be recognised that the assessment results on performance of seed origins have to be viewed through a lot of noise caused by events early in the life of these trials that might have overridden true responses of different seed origins to the growth potential at each site as well as requiring large differences in survival and growth to reach statistical significance.

3.3.1. Plym 3 (Figure 8)

There were highly significant differences in survival and growth between blocks suggesting that coast redwood is sensitive to local environmental conditions during and after establishment.

Despite this block variation, overall survival of most seed origins was general good with the exception of the most southerly origin, Mt. Maro 1026, with only 10% survival. Survival was also lower (50-60%) in Napa 1017, Navarro River 1010 and Smith River 1004, but this difference was only statistically significant for the Smith River origin (Figure 8a).

For areas where more than one tree was sampled for seed, survival was similar for both sampled trees at Brookings and Ukiah, but differed by 25% between trees for Smith River and Napa.

There was no statistically significant continuous relationship between survival and latitude for origins from north of 38^{o}, with only the most southerly origin having poor survival (Figure 8c).

Height growth after 7 years fell into two overlapping groups of significance with the most southerly origin (Mt. Maro 1026) having the shortest height and the most northerly (Brookings 1001) the tallest (Figure 8b).

There was a small but significant quadratic relationship between height growth and latitude with again the greatest decrease occurring in the most southerly origin (figure 8d).

3.3.2. Alice Holt 147 (Figure 9)

In the single-replicate demonstration at Alice Holt, there was much more variation between origins in survival (Figure 9a). Survival was highest at more than 60% for Napa 1018, Navarro River 1011 and Brookings 1001 and was least for the two southerly origins.

There was no statistically significant relationship between survival and latitude (Figure 9c).

Generally, the three origins with highest survival were also the tallest (Figure 9b). However, relative height growth of the two southerly origins (Gorda 1029 and Mt. Maro 1025) was better than at Plym. The regression between of height and latitude was not significant (Figure 9d).

3.3.3. Alton 24 (Figure 10)

Survival ranged from 50-90% with no significant relationship with latitude (Figures 10a&c).

Height growth was also similar across most origins, though the most northerly origin (Smith River 1005) was the tallest (Figure 10b). The regression between of height and latitude was not significant (Figure 10d).

3.4. Conclusions

1. Coast redwood is resilient in that its ability to reshoot and coppice enables it to recover from browsing and frost damage.
2. Variation in survival and growth between individual trees within a population can be as much as differences between populations.
3. Southerly origins from south of the San Francisco Bay area should be avoided.
4. These trials do not show any consistent variation between origins from north of San Francisco, with mid-range origins performing as well as, if not slightly better than the most northerly origins. However, much more detailed sampling of populations from along the range is needed to test this further.

Table 4. Seed sources planted in three seed origin trials.

Area name	Tree code	Plym 3 3 replicates	Alice Holt 147 1 replicate	Alton 24 3 replicates
Brookings	1001	✓	✓	
	1003	✓		
Smith River	1004	✓		
	1005	✓	✓	✓
Gasquet	3			✓
Ukiah	1007			✓
	1008	✓	✓	
	1009	✓		✓
Navarro River	1010	✓	✓	✓
	1011		✓	
Napa	1016	✓	✓	✓
	1017	✓	✓	
	1018	✓	✓	✓
Mt. Maro	1025		✓	
	1026	✓		
Gorda	1029		✓	
Monterey	1			✓
Richardson Grove	1			✓

Table 5. Details of three coast redwood seed origin trials.

Experiment name	P Year	Location	Design	Age at last assessment
Plym 3	1965	Buckland, Devon. SX 465668	Randomised block, 3 reps.	7 years
Alice Holt 147	1965	Alice Holt, Surrey. SU804424	Single plot demonstration	7 years
Alton 24	1968	Weston Common, Hants. SU 697442	Randomised block, 3 replicates	Height 6 years Survival 2 years

Table 6. Ecological Site Classification parameters and site suitability for *Sequoia sempervirens* for experiment sites using default soil inputs. (ESC version 3. http://www.eforestry.gov.uk/forestdss/objective.do?app=esc)

Experiment name	AT5	CT	DAMS	MD	Annual rainfall (mm)	Soil - SMR	Soil - SNR	ESC Suitability For RSQ
Plym 3	1936.5	7.5	13.3	151.8	1264.3	Fresh	Poor	Suitable
Alice Holt 147	1770.4	10.3	13.1	185.8	784.5	Very moist	Poor	Suitable
Alton 24	1649.7	10.2	13.6	168.5	841.7	Slightly Dry	Rich	Suitable

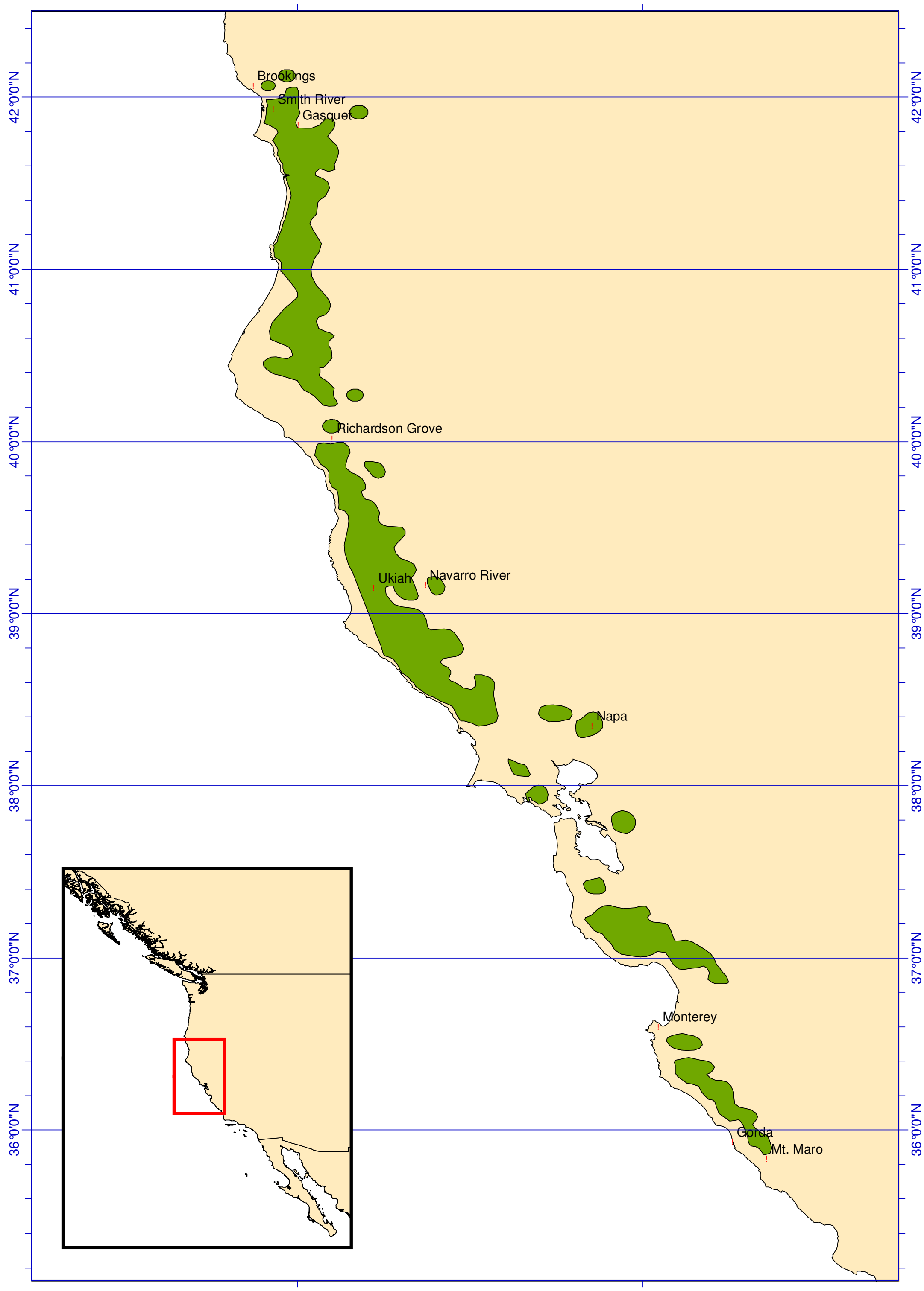

Figure 7. Approximate locations of seed origins of *Sequoia sempervirens*.

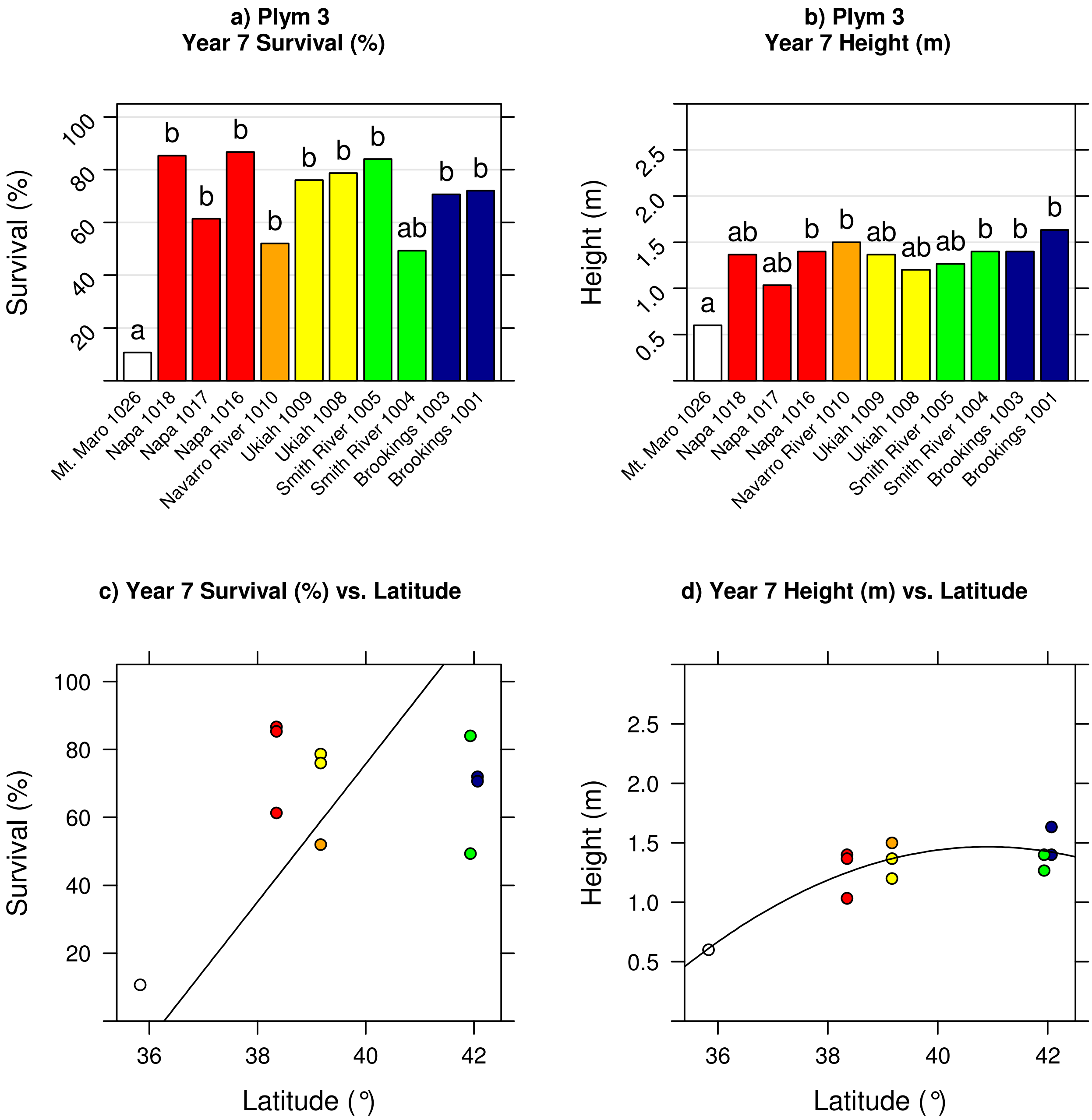

Figure 8. Average a) survival and b) height of different seed origins of *Sequoia sempervirens* after 7 years in Experiment Plym 3. Bars for trees from within the same collection location are coloured the same; bars sharing the same letter are not statistically significant. Scatter plots of c) survival and d) height against latitude of origin. Lines are statistically significant fitted relationships from GLM (survival) and quadratic regression (height).

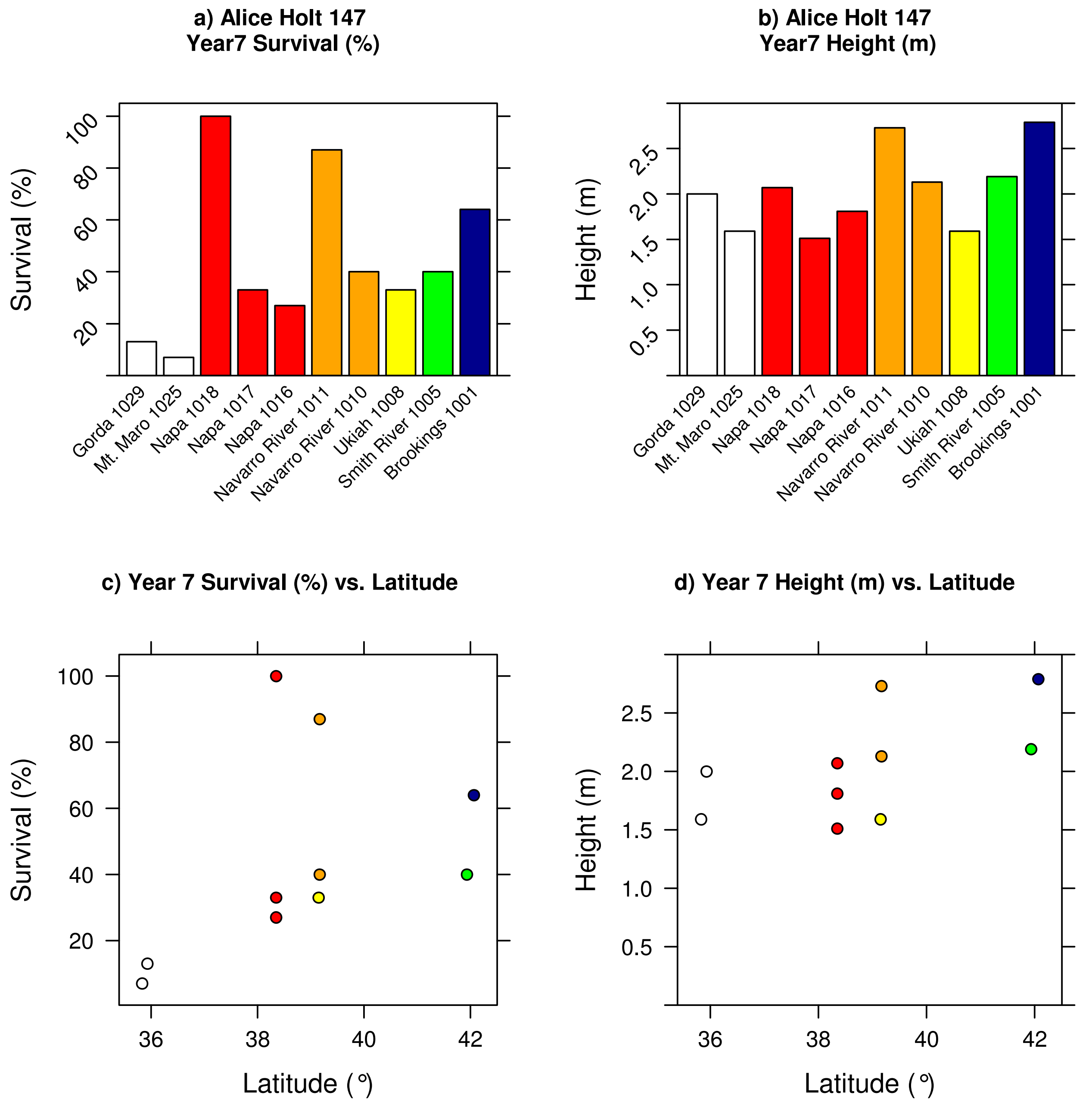

Figure 9. Average a) survival and b) height of different seed origins of *Sequoia sempervirens* after 7 years in the demonstration experiment Alice Holt 147. Bars for trees from within the same collection location are coloured the same. Scatter plots of c) survival and d) height against latitude of origin; fitted models from GLM (survival) and quadratic regression (height) were not statistically significant.

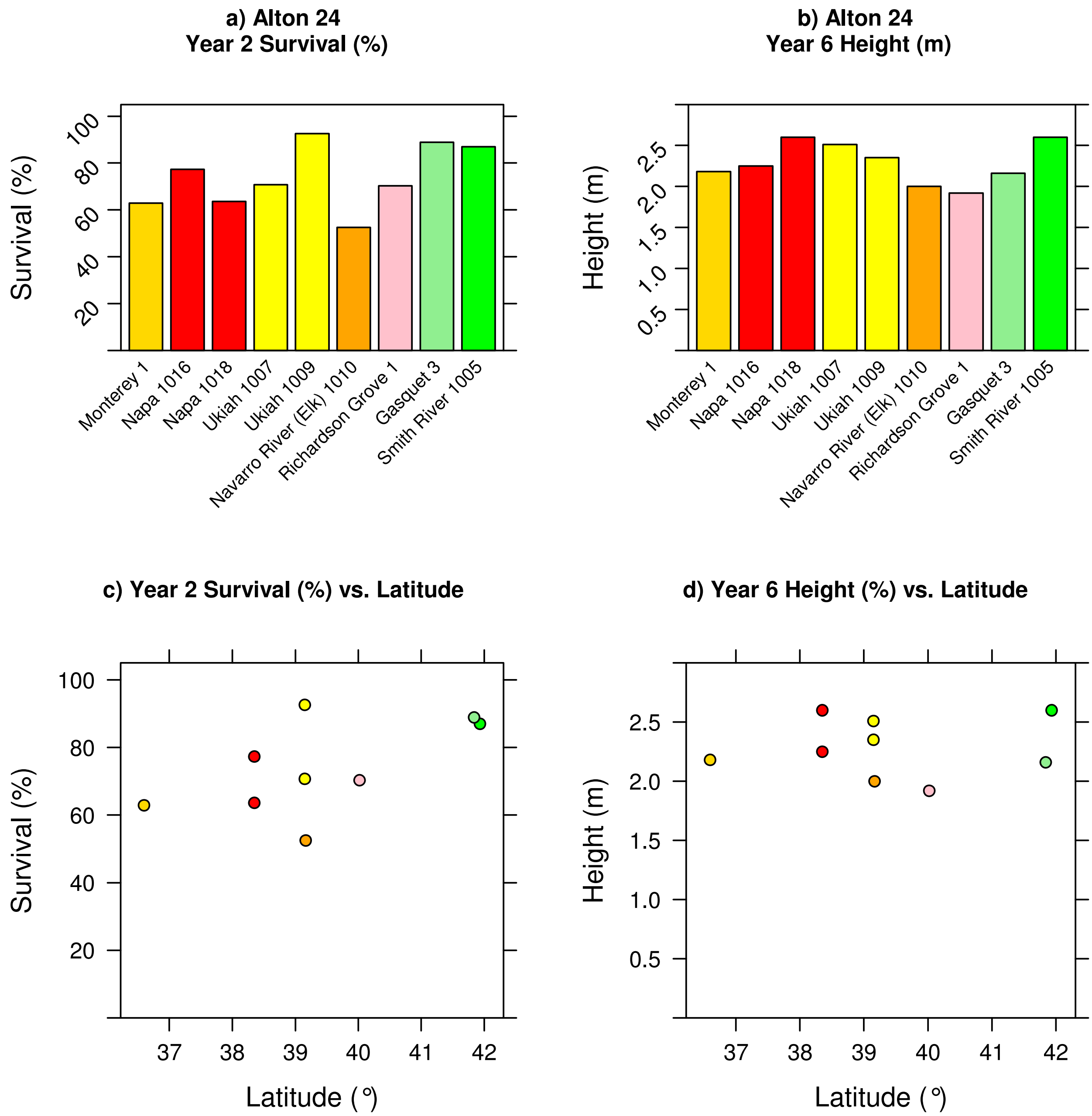

Figure 10. Summaries of average a) survival and b) height of different seed origins of *Sequoia sempervirens* after 7 years in Experiment Alton 24. Plot data were not available for statistical analyses. Bars for trees from within the same collection location are coloured the same. Scatter plots of c) survival and d) height against latitude of origin; fitted models from GLM (survival) and quadratic regression (height) were not statistically significant.

4. References and acknowledgements

Forestry Commission, 1965. Seed Identification Numbers. Forestry Commission Research Branch Paper No. 29.

Lines, R. 1987. Choice of Seed Origins for the Main Forest Species in Britain. Forestry Commission Bulletin 66. London: HMSO.

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