The potential suitability of provenances of *Eucalyptus gunnii* for short rotation forestry in the UK

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SUMMARY: Climate change and concern about the security of energy supplies has raised the profile of renewable energy, of which one potential source is woody biomass. One approach to growing woody biomass is short rotation forestry, which involves growing single stems over rotations of between 10 and 20 years. A genus that would appear particularly productive is *Eucalyptus*; however, only a few species are suited to the UK climate. One of the most cold-tolerant species is *Eucalyptus gunnii* and the potential growth and survival of provenances of this species was tested in a series of trials established across the UK in 1981. This paper reports twenty-five year results of a trial at Glenbranter, southwest Scotland. Of those provenances only those from Lake Mackenzie, Tasmania were both well–adapted to the extremes of the UK climate and exhibited useful rates of growth. The two other species in the trial, *E. glaucescens* and *E. urnigera*, were not suited to the site.

Introduction

The climate is changing and renewable sources of energy offer an opportunity to reduce the amount of fossil fuel combustion that contributes to the greenhouse gas emissions that are driving this change. One form of renewable energy is woody biomass, which offers a carbon-lean source of energy. Furthermore, although concerns about climate change are a major driver in UK energy policy, security of energy supplies is becoming increasingly important. McKay (2006) cited three main reasons for this:

- UK Economic reserves of deep mined coal in the UK are likely to be exhausted within 10 years.
- It was expected that the UK would become a net importer of natural gas by 2006 (which has proved correct) and of oil by 2010.
- By 2020 if present growth in demand continues the UK could be reliant on imported energy for three quarters of its needs.

This policy climate offers considerable potential for the development of woody biomass as a source of energy. In the past the development of woody biomass crops has centred on short-rotation coppice (SRC). SRC involves growing multi-stemmed woody material over short rotations, usually of less than five years. Yet despite SRC having relatively high rates of growth and being productive on short rotations, material used in SRC, such as willow (*Salix* spp.) and poplar (*Populus* spp.) fail on six other criteria for an ideal fuel wood (Ramsay, 2004). A suitable tree for fuel should:

1. Produce high density wood.
2. Have suitable chemical characteristics.
3. Exhibit low moisture content.
4. Be easily harvested.
5. Be harvested using conventional machinery.
6. Be capable of being harvested all year around.

Willow and poplar SRC produces small diameter material with a high moisture content, low wood density and a high bark content, which can produce corrosive substances when burned. It is harvested using converted agricultural machinery and can only be harvested when the soil is relatively dry. As such, attention has turned to the use of short-rotation forestry (SRF), which differs from SRC in that the material is single-stemmed and the rotation is normally longer, usually being greater than ten years and, according to Hardcastle (2006), yielding material of between 10 and 20 cm diameter at breast height (dbh). SRF can be harvested using conventional forestry harvesting machinery.

SRF also offers the opportunity of substituting more fossil fuel. In the recently produced 'A Woodfuel Strategy for England' (Forestry Commission England, 2007) a table comparing total carbon savings for various silvicultural options, including SRF eucalypt was presented. This is reproduced in Table 1 and indicates that in terms of the amount of carbon sequestered and the greenhouse gas emissions avoided eucalypt SRF is an attractive option.

One species that is considered to have potential is *Eucalyptus gunnii* Hook.f. (Hardcastle, 2006), a cold-tolerant eucalypt endemic to Tasmania (Williams and Potts, 1996). Previous work based on early assessments of trials has shown that there are considerable differences in growth and survival between provenances in the UK (Evans, 1986). This article describes the results of an assessment of twenty-five year performance of provenances of *E. gunnii* at Glenbranter, southwest Scotland.

Background to *Eucalyptus gunnii*

Eucalyptus gunnii is considered to be one of the hardiest of the eucalypts. It is found in cold, open, alpine areas of Tasmania where it occupies sites with poor soil drainage (Potts, 1983). In the Central Plateau area, at altitudes of 1000m to 1100m, on sites that border frost hollows it forms extensive areas of woodland (Potts, 1983). There is quite considerable variation in the *Gunnii* complex, a grouping of closely related species, subspecies and varieties that includes not only *E. gunnii* and its varieties and subspecies but also *Eucalyptus urnigera* Hook.f. There is some discussion as to whether *E. gunnii* and *E. archeri* Maiden & Blakely should be treated as separate species; however, *E. divaricata* McAulay & Brett is recognised as a variety of *E. gunnii* (Williams and Potts, 1996). In this paper *E. archeri* is considered to be *E. gunnii* ssp. *archeri*, following the classification of Potts and Reid (1985, cited in Williams and Potts, 1996). There would appear to be two main drivers in the variation in *E. gunnii*: the intensity of the alpine climate and the location of the population in relation to a gradient between open woodland in the sub-alpine, frost-hollow habitat and the more benign mixed eucalypt/rain forest habitat (Potts, 1983).

In sheltered, low altitude parts of the southern slopes of the Central Plateau *E. gunnii* can exceed 30m in height, whereas the trees in the low lying areas of the button grass plains open trees rarely exceed 5m in height and are often of a malee habit (ie. exhibits multiple stems arising from underground lignotubers). *E. gunnii* ssp. *archeri* generally occurs as a malee or small tree but will occasionally grow tall (20-30m) (Potts, 1983). This variation in size and growth habit means that selecting the correct provenance is particularly important even for biomass. In short rotation forestry a single straight stem is useful in facilitating mechanical harvesting and ensuring efficient stacking of material.

Table 1. Woodland creation options.
The figures are in carbon saved in tonnes per hectare and are from Forestry Commission England, (2007) Figures in parentheses assume no clearfell at the end of the rotation with an objective of continuous cover management.

Public good	SRC willow	SRF ash	SRF eucalypt	Native woodland	Conifer
Additional carbon stored over 5 years	8.6	28.5	43.5	8.9	13
GHG emissions avoided over 5 years	16	0	0	0	0
Additional carbon stored over 20 years	8.6	70.9	67.7	35.4	52.1
GHG avoided over over 20 years	64.0	59.2	96	9.8	9.8
Additional carbon stored over 100 years	8.6	70.9	67.7	115(279)	87.2
GHG emissions avoided over 100 years	320	296	480	133(72.8)	220

E. gunnii is not widely planted as a plantation species but by 2003 in France 650ha had been planted and a further 350ha of a *E. gunnii* x *E. dalrympleana* Maiden hybrid had been established. In France *E. gunnii* was recognised as being suited to sites where minimum temperatures do not drop below -18°C (AFOCEL, 2003a). This threshold is supported by work by Sheppard and Cannell (1987) who subjected seedlings of Lake Mackenzie provenances of *E. gunnii* to temperatures of -16°C without damage. However, it is not only minimum temperatures that defines suitable planting sites because frost resistance is built up in response to a slow reduction in temperature (Paton, 1983; Sheppard and Cannell, 1987); early or late frosts even in relatively warm sites present a hazard. In addition a major hazard is frozen ground which will kill roots. In the native habitat of *E. gunnii* the ground in winter is often insulated by a layer of snow (Pryor, 1976).

The provenance trial

The trial reported in this study forms part of a network of species and provenance trials that were planted in 1981 to test the suitability of a wide range of temperate eucalypt species. The location of the trial is near the Forestry Commission Office at Glenbranter Forest, Argyll, southwest Scotland, grid reference NS 095968. The site is on a moderately steep, south-easterly facing slope and soils comprise shallow brown earths and surface water gleys. Part of the site

Table 2. The origin of seed lots at the Glenbranter trial (Forestry Commission, 1980).

Seed lot	Species	Origin/provenance	Altitude	Dimensions of parent tree
1	*E. gunnii*	Miena, Tasmania – Lagoon Isles near Steppes	1000	
2	*E. gunnii*	Forest Marsh, Tasmania	1000	25x130
3	*E. gunnii var divaricata*	Miena, Tasmania	1100	20 x 150
5	*E. gunnii*	Western Mountains, Tasmania	1235	
9	*E. gunnii*	19 Fleet Road, Fleet, Surrey		12m x 25cm
11	*E. gunnii* var *archeri*	Forest Marsh, Tasmania	1000	25 x 130
12	*E. gunnii* var *archeri*	Western Mountains, Tasmania	1310	
14	*E. gunnii*	Clairac, Gironde, France,AFOCEL		
16	*E. gunnii*	Ex Glenbranter Experiment 6, P68		
19	*E. gunnii*	Devinas, Gironde, France,AFOCEL		
20	*E. gunnii*	Moliets, Landes France,AFOCEL		
100	*E. gunnii*	Lake MacKenzie, Tasmania No 1	1100-1200	7m x 22 cm
101	*E. gunnii*	Lake MacKenzie, Tasmania No 2	1100-1200	8m x 22cm
102	*E. gunnii*	Lake MacKenzie, Tasmania No 3	1100-1200	13.5m x 28cm
103	*E. gunnii*	Lake MacKenzie, Tasmania No 4	1100-1200	14m x 30cm
104	*E. gunnii*	Lake MacKenzie, Tasmania No 5	1100-1200	15m x 35cm
105	*E. gunnii*	Mt Cattley, Tasmania	680	17m x 30cm
106	*E. gunnii*	Mt Cattley, Tasmania	680	22m x 40cm
107	*E. gunnii*	Mt Cattley, Tasmania	680	20m x 35cm
109	*E. gunnii*	Mt Cattley, Tasmania	680	25m x 120cm
110	*E. gunnii* var *archeri*	Ben Lomond, Tasmania	1200	7m x 12cm
111	*E. gunnii* var *archeri*	Ben Lomond, Tasmania	1200	5m x 10cm
113	*E. gunnii* var *archeri*	Ben Lomond, Tasmania	1200	5m x 10cm
142	*E. glaucescens*	Mt Erica, Victoria	1070	
143	*E. glaucescens*	Mt Tingi Ringi, New South Wales	1420	
144	*E. glaucescens*	Tinderry Mts, New South Wales	1400	
145	*E. glaucescens*	Guthega, New South Wales	1550	
146	*E. glaucescens*	Mt Erica, Victoria	1340	
147	*E. glaucescens*	Mt St Gwinear, Victoria	1372	
217	*E. urnigera*	Mt Misery, Tasmania	850	

Table 3. Scoring for spruce competition (Cope, 2007).

Score	Level of competition	Description	Stems present
0	No spruce competition	No spruce stems or overhanging branches in the plot	None
1	Little spruce competition	Few spruce stems or overhanging branches from neighbouring plots within the plot	0-2
2	High spruce competition	Many spruce stems through the plot	>2

was previously planted with Norway spruce (*Picea abies* (L) Karst) and Sitka spruce (*Picea sitchensis* (Bong) Carr) plantations, while the other part was originally used for a Sitka spruce seedling experiment.

Prior to planting residual spruce from a previous experiment were killed using herbicide and billhooks, while a later application of Atrazine (a selective systemic herbicide produced by Novartis) was used to control weed growth on the remainder of the site. The experiment was planted in 1981 and contains provenances of *E. vernicosa* Hook. f, *E. pauciflora* Seb. Ex Spreng and close relatives, *E. delegatensis* R.T. Baker, *E. nitens* (Deane & Maiden) Maiden and also several other *Eucalyptus* species. However, this analysis focuses on a section of the trial that was planted primarily with provenances of *E. gunnii* and of its subspecies *E. gunnii* ssp. *archeri* and variety *E.gunnii* var. *divaricata*. Six seed lots of *E. glaucescens* Maiden & Blakely and one of *E. urnigera* Hook. f., a close relative of *E. gunnii* were also part of the trial and have been included. Overall, 34 seed origins were tested, in plots of nine trees, replicated three times in a randomised complete block design. Details of the origin of the seed lots are described in Table 2. The trial was fertilised with URP (Udaipur rock phosphate) at 75 kg per hectare prior to planting (Forestry Commission, 1980). Early in the life of the trial Sitka spruce natural regeneration colonised parts of the trial and this has to an extent impacted on the results.

Methods

Field measurements

Diameter at breast height (dbh) of all trees in the trial was measured following Forestry Commission conventions (Matthews and Mackie, 2006) using a centimetre graduated girth tape. As height is a more time-consuming measurement two heights were measured in each plot, selected at random using random-number tables generated in Excel. The trees in each seed lot showed consistency in their height so where a tree that was selected was missing or broken, another number was selected from the random-number table. Height was measured optically using a Vertex digital clinometer (a digital device, manufactured by Haglof AB, Sweden) adopting measurement conventions used by the Forestry Commission (Matthews and MacKie, 2006).

The impact of Sitka spruce regeneration in each plot was assessed subjectively. Due to the small size of the plots, simple measures of site occupancy such as basal area could not be used. This was because in many cases the competition was from spruce foliage from trees that originated from outside the plot. The level of competition fell into three categories, which were assigned a score. These are shown in Table 3 above.

Derived parameters

Two volume equations were used to calculate a standing volume and mean annual increment (MAI). The first step was to calculate average tree volumes based on the mean dbh and mean heights of the seed lots. Two volume equations were used to calculate the tree volumes of *E. gunnii* provenances. Tree volumes were then multiplied by stocking density (1,840 stems/ha) and percentage survival to obtain a volume per hectare, which in turn was divided by the age (twenty-five years) to determine the MAI.

The first volume function, developed from measurements of *E. gunnii* and an *E. gunnii* x *E. dalrympleana* hybrid in France, was as follows:

Volume in $dm^3 = -5.04+(0.03556 \times dbh^2) \times height$
(AFOCEL, 2003b)

The other volume function was one used by Shell in Chile to estimate volume of eucalypt stands (Purse and Richardson, 2001). This applies a breast height form factor of 0.35 and so volume is calculated by:

Volume in $m^3 = (dbh/100)^2 \times height \times 0.35$
(Purse and Richardson, 2001)

For both equations dbh is in centimetres and height is in metres.

Results and discussion

The winter of 1981-82 proved to be one of the coldest in decades and survival of the trees in their first year of growth was poor. The trial was beaten up but records of survival over the first two years of establishment have errors. It was found that the number of trees in plots plus the number used in the beat up was less than the number finally recorded in the plot. This is unfortunate as much of the mortality might be expected to occur during the early years of establishment. For the present analysis of the potential productivity of *E. gunnii* the survival of provenances compared to that at the year 3 assessment has been used.

Mean dbh, height and percentage survival (relative to year 3 survival) were calculated for all seed lots and are shown in Table 4. Volume per ha and

Table 4. Results of a twenty five year assessment of dbh, height and survival since age 3 years (Cope 2007) and of MAI calculated using the Shell volume function in m³/ha/year. Standing volume and MAI from the AFOCEL function has been omitted as differences from those calculated using the Shell function are inconsequential.

Seed lot	Species	Dbh (cm)	Height (m)	Survival (%)	Shell vol/ha (m³/ha)	Shell MAI (m³/ha/year)
1	*E. gunnii*	20.7	18.7	80	412	16.5
2	*E. gunnii*	19.5	19.9	38	185	7.4
3	*E. gunnii* var *divaricata*	22.9	18.6	36	227	9.1
5	*E. gunnii*	14.2	10.5	40	55	2.2
9	*E. gunnii*	19.2	14.7	85	297	11.9
11	*E. gunnii* var *archeri*	16.2	15.8	88	235	9.4
12	*E. gunnii* var *archeri*	26.0	24.9	33	357	14.3
14	*E. gunnii*	8.0	9.2	20	7	0.3
16	*E. gunnii*	20.0	21.0	78	422	16.9
19	*E. gunnii*	14.0	18.8	25	60	2.4
20	*E. gunnii*	21.3	15.5	29	132	5.3
100	*E. gunnii*	24.6	18.1	94	665	26.6
101	*E. gunnii*	19.5	17.9	86	377	15.1
102	*E. gunnii*	19.3	16.8	100	402	16.1
103	*E. gunnii*	21.5	19.7	96	562	22.5
104	*E. gunnii*	15.5	16.6	100	257	10.3
105	*E. gunnii*	11.0	6.3	100	50	2.0
106	*E. gunnii*	12.2	18.2	39	67	2.7
107	*E. gunnii*	10.3	11.1	31	22	0.9
109	*E. gunnii*	7.6	5.3	29		0.2
110	*E. gunnii* var *archeri*	19.5	14.6	67	240	9.6
111	*E. gunnii* var *archeri*	20.6	17.5	92	440	17.6
113	*E. gunnii* var *archeri*	24.5	16.9	100	655	26.2
142	*E. glaucescens*	22.8	22.0	100	737	29.5
143	*E. glaucescens*	4.5	7.1	31	2	0.1
144	*E. glaucescens*	13.5	15.0	29	50	2.0
145	*E. glaucescens*	16.3	16.8	69	187	7.9
146	*E. glaucescens*	19.9	14.8	82	310	12.4
147	*E. glaucescens*	23.5	21.7	71	547	21.9
217	*E. urnigera*	15.3	18.2	67	185	7.4

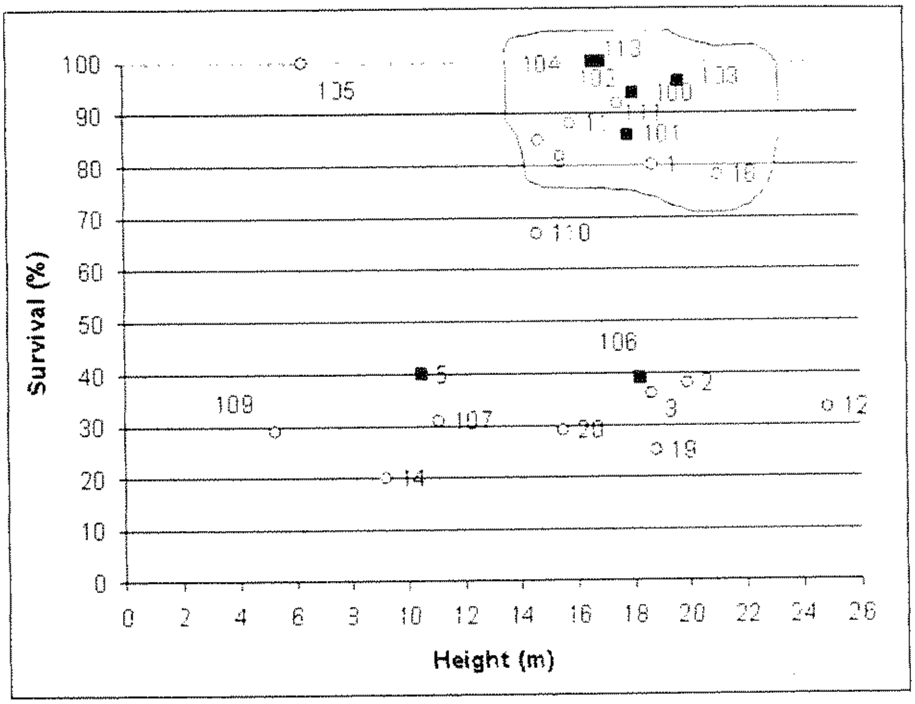

Figure 1. Height and survival (from year 3) of the species and provenances assessed at Glenbranter. Those provenances with black squares as markers showed >50% survival at year 3. The encircled area indicates provenances with best percentage survival and height growth since age 3 years.

mean annual increment (MAI) for each provenance are also shown in Table 4.

E. gunnii would appear to be one of the best adapted eucalypt species to the UK climate. Although growth rates are lower than species such as *E. nitens*, it is considerably more cold-hardy. Overall, the provenances that have performed well are those identified in the early results published by Evans (1986). A graph of survival and height growth of the seed lots is shown in Figure 1. The results indicate that if *E. gunnii* is to be planted as SRF to supply biomass, it is crucial that material be used from an appropriate provenance.

Initially it had been intended to analyse the data on performance of provenances in trial using ANOVA, but the small numbers of trees surviving in some plots precluded this approach. Also, there proved to be anomalies in the data on initial numbers of trees, due to poor record keeping of numbers of plants in beat up operations. Consequently, number of trees surviving at age 3 years was used as a baseline for this study. These 'survival at age three' data varied from 0 trees to 9 trees per plot

Due to these difficulties with the data, a pragmatic approach to analysis was adopted. As a first stage in the analysis all seed lots that showed less than 50% survival after three years, based on initial planting number, were excluded. These origins are unlikely to be suited to a role in forestry for biomass production, where initial site capture is crucial. The provenances that were excluded are shown in Figure 1 as white circles and it can be seen that some of those seed lots have exhibited good survival since year 3. However, they are not considered suited to planting in the UK, as their poor survival through the exceptionally severe winter in their first year of establishment showed they were poorly adapted to extremes in the UK climate.

When those seed origins with poor three year survival were excluded, nine seed lots remained for further analysis, these being seed lots of *E. gunnii* (5, 100, 101, 102, 103, 104, 106), a seed origin of *E. glaucescens* (144) and that of *E. urnigera* (217). A statistical analysis comparing height, dbh and survival was considered at this stage but was rejected. The majority of the superior seed lots; 100, 101,102, 103 and 104 are from the same origin but are collections from single trees. Thus, the minor differences in survival and growth between these seedlots represent differences between individuals within a superior origin and so further analysis was not undertaken.

In Figure 1 the best performing seed lots of *E. gunnii* in terms of and growth and survival since year 3 are shown in the encircled area. Excluding those with poor survival to year 3, the best performing provenances originate from Lake MacKenzie, Tasmania (seed lots 100, 101, 102, 103, 104). These showed good survival through the exceptionally cold winter of 1981/82 and have grown well since. Consequently, they are the only origins recommended for planting in the UK. Those seed origins of *E. glaucescens* and *E. urnigera* that exhibited good early survival have proved to be poor in terms of growth rates and are not considered to have potential on sites such as Glenbranter.

Other provenances performed well during the milder winters after 1981/82 such as two of the three from Ben Lomond (seed lots 111, 113), which are *E. gunnii* ssp. *archeri*. One origin of *E. gunnii* ssp. *archeri* from Ben Lomond (seed lot 110) performed less well, exhibiting both poorer growth and survival. Material collected in the UK from *E. gunnii* trees in Surrey (seed lot 9), and also an earlier planting at Glenbranter (seed lot 16), have also performed well since age 3 years. This may suggest that within a generation there has been some development of a UK land race. The remaining origins (seed lots 1, 11) from moderate altitudes of 1,000m showed poor survival in the first three years, but good survival thereafter.

Those provenances with poor growth and survival both at age 3, and from then until now, included *E. gunnii* from Mount Cattley, Western Mountains and the AFOCEL material. Seed lot 105 appears to have excellent survival, but this is since 1984 as early survival over the winter of 1981/82 was very poor. Both seed lots for Miena, (seed lots 1, 3) Tasmania have grown well after considerable mortality in the winter of 1981/82. However, survival of the *E. gunnii* var *divaricata* (seed lot 3) has been disappointing. Performance of the other species in the *Gunnii* group, *E. urnigera* and *E. glaucescens* was poor, except one *E. glaucescens* seed lot (142) from Mount Erica, Victoria which had the best growth and survival from age 3 but where only 11% of the original trees survived the cold winter of 1981/82.

When considering the performance of the provenances some care must be taken, given that the seed for many would appear to have been collected from a single mother tree and as such the trial is testing individuals from within a provenance rather than the provenance itself. Considerable variation between individuals can be seen in the collections from Mount Cattley (105, 106, 107, 109), but less so in those from Lake MacKenzie (102, 103, 103, 104).

The natural regeneration of Sitka spruce may have had an impact on the growth of the eucalypts. As a starting point to analysis graphs were produced of height and dbh (Figure 2) against spruce competition score. These showed no obvious trends, with both poor and good performing seed origins being found in areas of high spruce competition and vice versa and further analysis was not undertaken. It has therefore been assumed that the spruce has had little effect on the overall ranking of the seed lots.

Evans (1986) collated the results for the *Gunnii* group across the 1981 trials. His early findings are largely supported by the results from Glenbranter. Evans (1986) found that:

- The *E. gunnii* species complex has greater potential hardiness than *E. glaucescens* and *E.*

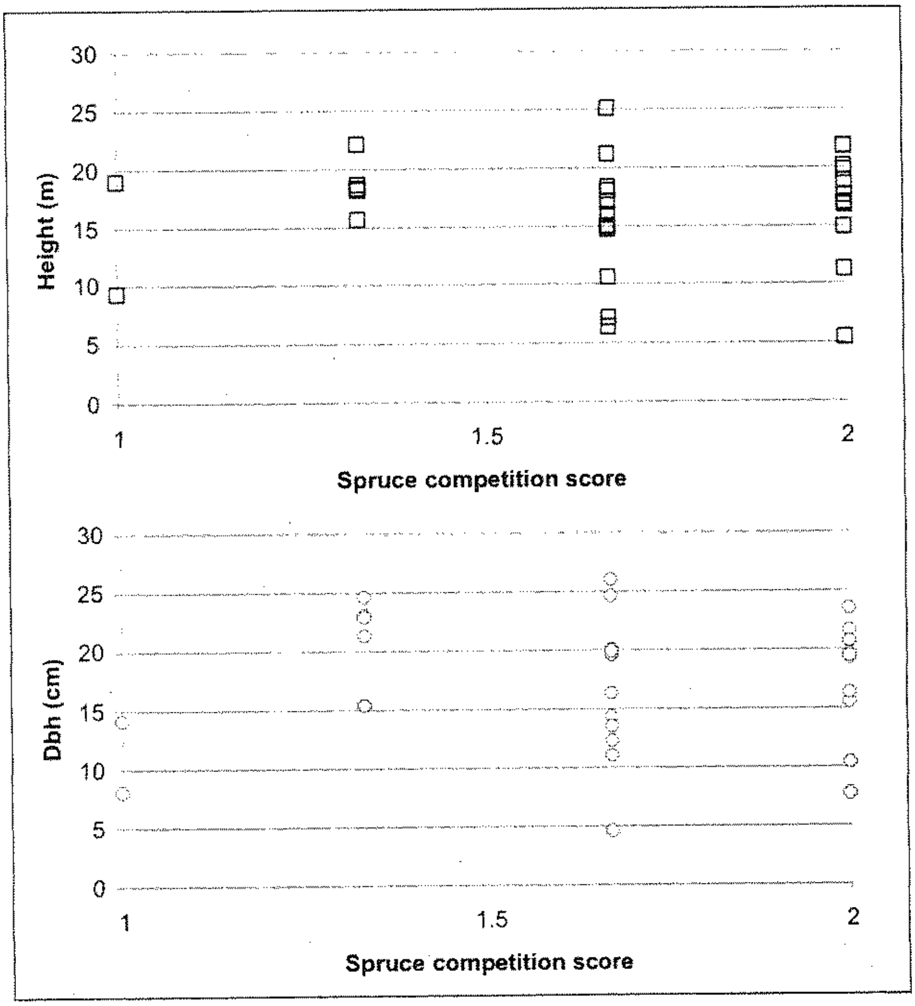

Figure 2. Height of seed lots against spruce competition score and dbh of seed lots against spruce competitionn score.

urnigera. This is supported by the Glenbranter results.

- The *E. gunnii* ssp. *archeri* is no more cold tolerant then *E. gunnii* and is of less interest as it is likely to grow only to a small stature. If the product is biomass grown on short rotations its stature as a small tree when mature is less of a concern, however early survival of the origins at Glenbranter were disappointing.

- Within *E. gunnii* there are major differences in hardiness between and within provenances. Evans (1986) recommended Central Tasmanian provenances from 1100m as being those best suited to the UK climate. This is confirmed by the results from this assessment; those from lower altitudes, such as Mount Cattley have generally performed poorly.

- The French material (seed lots 14, 19 and 20) was poorly adapted to our climate, which is confirmed by the results from this assessment.

Volume per hectare was calculated using the volume functions from France and Chile. The volumes obtained were unreasonably high, with a maximum of about 740 m^3/ha for both functions at about 25 years of age. In France *E. gunnii* and *E.* x *gundal* will yield about 200 m^3/ha on a twelve year rotation, giving a MAI of approximately 17 m^3/ha/year. Calculating MAI from the volumes obtained using either the French and Chilean functions gave MAI for the most successful seed lot at Glenbranter of around 27 m^3/ha/year and higher for a provenance of *E. glaucescens*. There are likely to be a number of sources of error. Caution should always be exercised when scaling up results from small, experimental plots. However, a more obvious source of error is the volume functions themselves. The French equation was developed from younger stands of *E. gunnii*, while the Chilean one will have been based on species other than *E. gunnii*. It is interesting, however, that the tree volumes calculated using the two functions are almost identical, varying by only a few percent. Given the high volumes calculated by these volume equations there is a need to develop one specifically for older stands in the UK and to assess the precision of these functions in estimating volumes of young stands in the UK (see Figure 3).

It would be of considerable use to destructively sample some of the larger blocks of *E. gunnii* planted by the Forestry Commission. This could provide two important pieces of information. First, stem analysis would allow provisional growth curves to be constructed, enabling the age of maximum MAI to be determined. Second, the same trees could be used to create a volume equation for older trees, which would provide the basis for a more reliable estimate of the MAI from different seed lots in the Forestry Commission's *E. gunnii* provenance trials.

In conclusion, this analysis confirms the earlier findings on the suitability of provenances of *E. gunnii* to UK conditions. If planting *E. gunnii*, seed should be used that is sourced from the Lake MacKenzie. In addition, this experiment was established on what was then a typical forestry

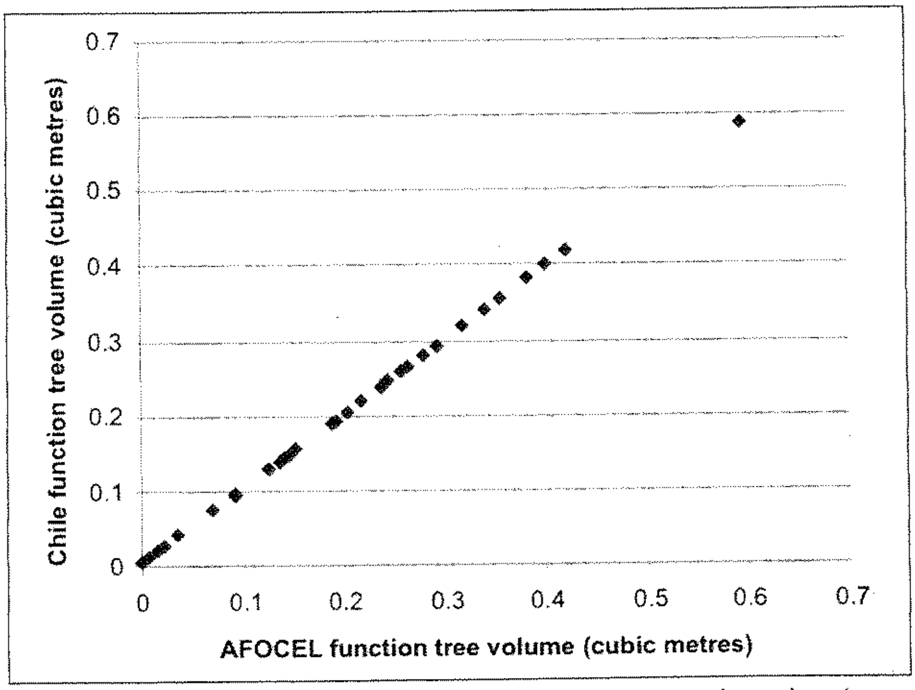

Figure 3. A comparison of tree volumes for provenances based on two parameter (dbh, height) volume functions developed by Shell in Chile and AFOCEL in France (AFOCEL, 2003b; Purse and Richardson, 2001).

site, yet SRF plantations are likely to be located on agricultural land. Table 1 showed the impacts of various SRF or SRC options in terms of carbon sequestered and greenhouse gas emissions avoided, however, it was not clear how these figures were derived (Forestry Commission England, 2007). Establishing a network of trials comparing these and other options for woodland creation is a priority to determine how best to use forests to store carbon and avoid greenhouse gas emissions in the UK.

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