Assessment of a *Eucalyptus* Provenance Trial at Thetford and Implications for *Eucalyptus* as a Biomass Crop in Lowland Britain

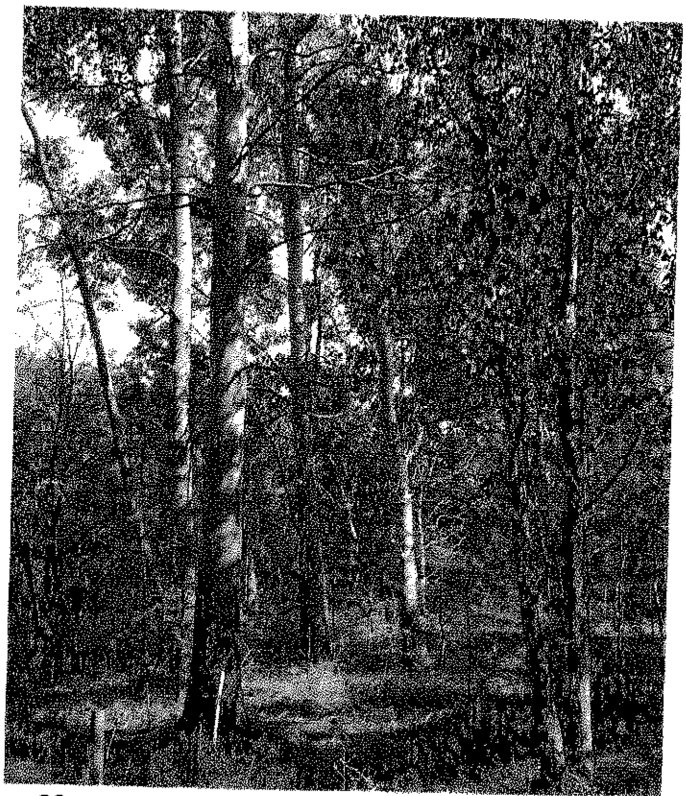
by C.J. Bennett and A.D. Leslie

SUMMARY: *Eucalyptus* has been largely rejected as a genus for production forestry in Britain despite several species surviving the winter of 1981/82, one of the severest winters since meteorological records began, and three subsequent severe winters. Twenty-one year results from a Forestry Commission species and provenance trial established in 1981 showed excellent growth for some seed origins of *Eucalyptus*. It is argued that *Eucalyptus* should be considered as an energy crop for lowland Britain given its fast growth, high wood density relative to other biomass genera and the suitability of its wood for small scale heat and power installations and co-firing in electricity generating plants.

Introduction

Eucalypts are used extensively as exotics in plantation forestry, with over 10 million ha being established to date (FAO 2001). Their ability to grow on poorer sites and their fast growth has made *Eucalyptus* an attractive genus for production forestry. Indeed, advances in tree improvement have enabled yields of 70m^3/ha/yr (FAO 2001) to 80m^3/ha/yr (Freezailah 1998) to be obtained from clonal *Eucalyptus* in research plots in Brazil. Even yields from operational plantings have been impressive, averaging 45m^3/ha/yr (Freezailah 1998).

In Britain the first successful introduction of a representative of the genus seems to have been that by James Balfour of Whittinghame of *E. gunnii* in 1846. During the 1870s and 1880s the genus became fashionable and by 1900 it is thought that over thirty species had been introduced to Britain (MacDonald et al 1957). By 1983 at least 100 species had been planted in the British Isles, although the majority failed due to our cold winters (Evans 1983). However, for many decades certain species have been recognised as being sufficiently hardy for production forestry in Britain. In an evaluation of damage to forest trees after an untimely and severe frost in May 1935 *E. gunnii* and *E. coccifera* were found not to have been damaged (Forestry Commission 1946), while a later Bulletin again describes *E. gunnii*, *E. niphophila*, *E. vernicosa* and *E. parvifolia* as being suitable for planting at low elevations. (Martin 1948 in MacDonald et al 1957). However, this data was somewhat anecdotal as seed sources used in early plantings were not recorded and performance was not tested through a rigorous experimental approach. A systematic approach to evaluating the potential of



22 year old *E. gunnii var. divaricata* at Lakenheath, Thetford - the hardiest eucalypt trialled in Eire. (Photo: Chris Bennett)

Location:	Elveden, Compartment 89, Thetford Chase, Suffolk OS Grid Reference TL772825	
Area:	0.41ha	
Physical Environment:	Altitude: Geology: Mean annual rainfall: Mean January temp: Mean July temp:	30m a.s.l. Gipping Till. Sandy brown earth over chalk 551mm 3.7°C 16.6°C
Aspect and shelter:	Aspect south-west. At planting, moderate shelter to the north-west and south-west by surrounding older plantations. Currently the eucalypts stand above neighbouring pine.	
Past management:	Previous stand of Yield Class 14 Corsican pine (*Pinus nigra var maritima*) planted in 1923 and felled in 1977/78.	
Planting Date:	May 1981	
Silviculture:	Pre-planting herbicide application of paraquat. Paper pots semi-pit planted at 2m x 2m spacing. Trees watered after planting. Bracken and competing vegetation cut by hand in 1981. Fertiliser applied 3 months after planting as 10kg/ha of K (muriate of potash = KCl) with 30 kg/ha NPK (25:9:9). Selected *E. nitens* were given Phostrogen two months after planting to try to encourage upright growth: Replicate 1: Root feed of 2g powder to 20cm radius around each tree. Replicate 2: Foliar feed of 2g per tree in 100 ml doses over 3 weeks.	
Experimental design:	Randomised block with eleven seed origins, replicated 4 times. Plots of 3 x 3 trees with 2m spacing between trees and 3m between plots.	

Table 1. Site and establishment details of the Thetford trial (Forestry Commission no date).

eucalypts in terms of growth and cold-tolerance in Britain began in the early 1980s, with the establishment of trials that coincided with the particularly severe winter of 1981/82, and was followed by three further severe winters in 1984/85, 1986 and 1987. This eliminated a large number of potential species and seed origins but three (*E. gunnii*, *E. niphophila* and *E. debeuzevillei*) were noted to be sufficiently frost hardy for British conditions (Evans 1986).

Evans' research (1986) showed that there are eucalypts suited to our climate, and so this paper will focus on the potential of certain cold-hardy eucalypts for rapid growth and their possible role as an energy crop, a role that has been recognised recently by other authors (Purse and Richardson 2001). The results of one of a series of Forestry Commission trials are described and supported by other data from recent plantings of eucalypts in Britain.

The Trial

The trial is a randomised block design testing nine species in four replicates. Site details (Forestry Commission no date, Evans 1983, Evans 1986) are described in Table 1. The details are a compilation of information from the experimental records (Forestry Commission no date) and two published papers (Evans 1983, Evans 1986). There are contradictions in the planting years and other establishment information between the field trial record and in the

Seed lot	Origin
E. gunnii var divaricata (3)	Miena, Tasmania, 1100m a.s.l., hardiest eucalypt trialled in Eire. Single tree collection.
E. gunnii (5)	Western Mountains, Tasmania, 1235m a.s.l.
E. gunnii (8A)	Seed from one tree, Lyndhurst, Hampshire, UK.
E. archeri (12)	Western Mountains, Tasmania 1310m a.s.l.
E. gunnii (16)	Glenbranter Experiment 6, Western Scotland.
E. coccifera (24)	Cornwall
E. debeuzevillei (29)	Seed from one tree, Bovey Tracy, Devon.
E. glaucescens (34)	Seed from one tree, Bovey Tracy, Devon.
E. niphophila (41)	Exeter University
E. nitens (45)	Plot 29, Kilmun, Argyll, Western Scotland.
E. nitens x *parvifolia* (49)	No record

Table 2. Origin of the *Eucalyptus* seed sources used in the Thetford Trial (Forestry Commission no date, Evans 1983). Note that some seedlots were collected from single trees.

papers. We have used the published date for calculations but otherwise the experimental records have been used. The origins of the provenances used in the trial are described in Table 2.

Methods

Measurements were taken on 10 April 2002. Diameter at breast height (dbh) was measured for all trees using a diameter tape and height measured using a clinometer for one tree per plot selected at random. Merchantable wood volume per tree was calculated using a form factor of 0.35 derived from work on eucalypts in Chile (Purse and Richardson 2001). The effective area of the trial was calculated by the length of area planted plus a 1.5m buffer each side of the last rows of trees multiplied by the width of the area planted plus a buffer of 1.5m each side. Stand volumes were calculated using the original stocking (1,850 stems/ha) multiplied by the percentage survival and tree volume.

Results and discussion

Eucalyptus is one of the fastest growing genera in plantation forestry (Evans 1980). Even in the climate of Great Britain they can excel; an *E. nitens* at Kilmun is recorded as possibly the fastest growing tree in the country, reaching a height of 19.5m and a dbh of 34cm at age nine years (Evans 1980). Despite this high productivity and the evidence that some species are suited to the British lowlands, interest in eucalypts waned in Britain and they were largely dismissed for large scale planting for timber (Kerr 1997). Interest in eucalypts has only resurfaced recently through their potential as biomass crops for energy. This discussion begins with a presentation and interpretation of the findings from the species and provenance trial at Thetford and then reviews the evidence for eucalypts as potential biomass crops in Britain.

The eucalypts at Thetford had been established for twenty one growing seasons. The most promising species in terms of growth and survival was *E. gunnii* (Table 3), which is known to be one of the hardiest eucalypts (Evans 1983, 1986). Comparisons between the survival of the *E. gunnii* at 6 and 18 months (Table 4) and the survival in 2002 shows that about half of those trees that remained after the second year have survived. However it is interesting to note that survival at 18 months of some seed lots, particularly *E. gunnii*, *E. archeri*, *E. glaucescens* and

Seed lot	Mean dbh (cm)	Dbh 95% CL (cm)	Mean Height (m)	Height 95% CL (cm)	Survival (%)
E. gunnii var divaricata (3)	23.1	5.5	19.6	3.6	42
E. gunnii (5)	23.2	1.3	20.8	1.6	53
E. gunnii (8A)	21.9	2.7	19.3	2.8	50
E. archeri (12)	24.9	5.2	20.5	4.0	47
E. gunnii (16)	19.5	1.7	12.8	3.9	33
E. coccifera (24)	30.8	N/A	12.9	N/A	11
E. debeuzevillei (29)*	15.5	N/A	10.8	N/A	11
E. glaucescens (34)	24.7	9.5	22.6	4.2	31
E. niphophila (41)	12.5	2.4	11.2	5.0	28
E. nitens (45)	0	0	0	0	0
E. nitens x *parvifolia* (49)*	0	0	0	0	0

Table 3. Results of dbh, height and survival of the *Eucalyptus* trial at Thetford after twenty-one growing seasons. **E. debeuzevillei* one replicate planted and *E. nitens* x *parvifolia* two replicates planted.

E. niphophila, was good despite the extreme winter of 1981/82. As such it seems unlikely that the subsequent mortality in these species was solely due to frost damage, and there is, in fact, some evidence on the site of some mortalities due to windthrow.

There was little difference in performance in terms of dbh or height between seed origins of this species with the exception of (16), which showed significantly (at 95% confidence) poorer height growth and worse survival. The one seed origin of *E. archeri*, a close relative of *E. gunnii*, looked very promising on this site. It should be noted that a number of the seed lots used in the trial, including two of *E. gunnii*, were from single tree collections. Consequently their performance may not be representative of the species/provenances as a whole.

Of the other species two showed moderate survival: *E. glaucescens*, which has grown rapidly, and the slower growing *E. niphophila*. *E. glaucescens* may offer potential for future planting, given its better form than *E. gunnii* and its excellent survival after the first two growing seasons. The *E. glaucescens* at Thetford, although suffering some incidence of multiple stems (assumed to be a result of the cold winters of early years) has good form. The species with highest potential productivity, *E. nitens*, showed no survival and is known to be less hardy than *E. gunnii* (Evans 1986). However, the *E. nitens* established in the recent trials described by Purse and Richardson (2001) are now showing exceptional promise in terms of yield and form, with very high survival to date.

Seed lot	% Survival October 1981*	October 1982
E. gunnii var divaricata (3)	97	83
E. gunnii (5)	95	83
E. gunnii (8A)	97	83
E. archeri (12)	97	67
E. gunnii (16)	97	89
E. coccifera (24)	92	33
E. debeuzevillei (29)	100	33
E. glaucescens (34)	92	78
E. niphophila (41)	84	64
E. nitens (45)	97	0
E. nitens x *parvifolia* (49)	95	28

Table 4. Results of survival in the *Eucalyptus* trial at Thetford in October 1981 (noted in file as October 1980) and October 1982 (Forestry Commission, no date).

The volume increment at Thetford, even of the better seed origins, is likely to be lower than its potential given the particularly cold winter of 1981/1982. Eucalypts are known to be highly sensitive to weed competition and yet weeding

Seed lot	BA per tree (m^2)	Merchantable Volume per tree (m^3)	Volume (m^3)/ha	MAI (m^3/ha/yr)
E. gunnii var divaricata (3)	0.053	0.36	284	13.5
E. gunnii (5)	0.054	0.39	382	18.2
E. gunnii (8A)	0.048	0.32	298	14.2
E. archeri (12)	0.062	0.44	386	18.4
E. gunnii (16)	0.038	0.17	103	4.9
E. coccifera (24)	0.095	0.43	88	4.2
E. debeuzevillei (29)*	0.024	0.09	18	0.9
E. glaucescens (34)	0.061	0.48	340	16.2
E. niphophila (41)	0.016	0.06	24	1.1
E. nitens (45)	0.000	0.00	0	0.0
E. nitens x *parvifolia* (49)*	0.000	0.00	0	0.0

Table 5. Basal Area (BA) and volume results derived from measurements taken at Thetford after twenty-one growing seasons. Merchantable volumes derived from a form factor of 0.35 (Purse and Richardson 2001), while volume/ha assumes stocking density of 1,850 stems/ha.

at Thetford involved cutting back of the weeds (Forestry Commission 1980), which is likely to have increased weed competition. In contrast in Brazil weeding is intensive, focussed on providing a virtually weed free zone. This weed free zone is maintained until canopy closure at about one year old (McNabb 1994).

Despite the poor survival, mean annual increments (MAI) of over 18m³/ha/year for the more successful seed origins over 21 years are impressive (Table 5), given that the previous stand on the site was Corsican pine (*Pinus nigra var maritima*) Yield Class (YC) 14. These growth rates from Thetford show that very high yields are achievable over short rotations. The cumulative volume production for Corsican pine YC 14 at 21 years old is 119m³/ha, with a mean tree volume of 0.08m³ (Edwards and Christie 1981). This compares with a merchantable wood volume of 386m³/ha and mean merchantable wood volume of 0.44m³ for the *E. archeri* seed origin at Thetford. It is only at 36 years of age that the Corsican pine achieves a similar cumulative volume (Edwards and Christie 1981). On this site it should, therefore, be possible to obtain at least twice the volume from a stand of *E. archeri* than from the currently favoured species, Corsican pine.

The growth data from the trial should be treated with some caution given that they are extrapolated from small plots, with a high proportion of trees being edge trees. However this order of productivity is known from other plantings of eucalypts in lowland England. A Forestry Commission stand of *E. gunnii* at Redmarley in Gloucester planted in 1986 and felled in the winter of 1997/98 gave an estimated MAI of 25m³/ha/yr (Jones pers comm. in Purse and Richardson 2001). The low stocking density of less than 1000 stems/ha on the plots at Thetford will have compromised productivity. As such it seems reasonable to assume that at higher stocking, on rotations of 10 to 12 years and with appropriate silviculture, Evans' (1986) prediction of MAIs of between 10 and 15 on former conifer YC10-14 sites is reasonable. Such crops could feasibly yield marketable thinnings after as few as 5 or 6 years.

The prediction by Evans (1986) is also supported by subsequent plantings in Great Britain by foresters familiar with eucalypts and using intensive silviculture, which have shown good survival and excellent growth. For example an eight-year old line planting of *E. nitens* at Tiverton in Devon at an equivalent stocking density of 1200 stems/ha yielded a basal area of 49.0 m²/ha and an estimated volume of 298 m³/ha. This was on a moderately exposed site at 130m a.s.l (Purse and Richardson 2001).

In recent years there have been changes in British forestry as typical planting sites are often on much better soils and subject to fewer extremes of climate, as afforestation has moved more into lowland Britain. The energy industry represents an emerging market for wood chips for heat and power generation. Since the FC trials were established biomass has increased in prominence. Yet despite the performance of the trees in these trials and Evans' recommendation of the suitability of *E. gunnii* as a species for forestry and biomass production in the UK (Evans 1983), this opportunity has not been exploited. However at present barriers to planting eucalypts exist. Recent Government policy has precluded all tree species other than poplars and willows from receiving grant aid for energy crop planting (Defra 2000) and there is often difficulty in obtaining approval for planting *Eucalyptus* under the Woodland Grant Scheme. Despite these constraints a valuable new set of independent trials has been initiated to demonstrate its suitability for wood fuel production. Results from these trials are discussed later in this article.

So, a new role for eucalypts in Britain may be as producers of biomass for energy. Growing eucalypts in lowland Britain for energy has certain attractions. In addition to rapid growth, the wood density of *E. gunnii* grown in Britain is around 400-500kg/m^3 (Evans 1983), potentially higher than that of willow at around 400 kg/m^3 (Nurmi and Hytönen 1994). The main advantage of high wood density in fuel feedstocks is that they have an inherently higher calorific value per unit volume than that of lower density wood. Significant gains can then be made in the handling, pre-processing and storage of lower volumes of material for a given energy yield. Evans (1983 p266) recognised the attractiveness of *E. gunnii* for this application, noting that "it is potentially higher yielding of dry matter than any other tree species that can be grown in Britain".

Co-firing is a process whereby biomass is burnt in conjunction with fossil fuels, usually in existing power stations, in order to reduce their carbon dioxide emissions. If wood were to become the preferred fuel for this application (and it does have many properties in its favour) this could have hugely beneficial implications for UK forestry. Co-firing using willow and poplar produces considerable quantities of chlorine and other minerals that may be deposited onto the internal components of boilers and prove to be corrosive, reducing service life and efficiency. Bark contains much higher proportions of these damaging minerals than clean wood and fuel derived from short rotation coppice displays high bark to wood ratios due to the small diameter of the material that is produced (Williamson 2002, Baxter 2002). Using larger sized material from eucalypts grown on longer rotations may be an answer.

An early set of seven biomass trials were established in 1981/82 in six locations across Great Britain gave indications of the potential of *Eucalyptus* as a biomass crop (Potter 1990). Only one species of eucalypt, *E. archeri,* was tested. Productivity of the eucalypt was on the whole comparable to: *Populus tricoicarpa* x *deltoides* RAP, *Salix burjatica* Korso and *Salix viminalis* Bowles Hybrid. The highest yield of the eucalypt was 14.2 odt/ha/year at Long Ashton (1m spacing and a 2 year rotation) and poorest was 2.5 odt/ha/year at Witney (2m spacing on a 2 year rotation) (Potter 1990). Both these sites were previously agricultural land. Potter (1990) noted that the initial growth of *E. archeri* was promising but that high mortality resulted from infection by silver leaf disease (*Chrondostereum purpureum*). A possible cause of this susceptibility was that the seed used for the trials had been collected from one tree in Tasmania (Potter 1990) and so had a restricted genetic base. Another source of mortality was the cold and Potter (1990) recommended that future trials use *E. gunnii*, a close relative of *E. archeri,* which was known to be more cold resistant.

At a later screening trial established at Long Ashton in 1986, the productivity of the *E. gunnii* was far superior to the alder (*Alnus rubra*) and the poplar and willow clones (*Salix viminalis* Bowles Hybrid) tested. The yield of the eucalypt ranged from 16-22 odt/ha/yr in comparison with the willow, the next most productive material, which only produced 7-8 odt/ha/yr (Mitchell et al 1993).

Unfortunately in this trial more than half of the stools of the *Eucalyptus* were killed again by silver leaf disease following cutting (Mitchell et al 1993). This susceptibility as well as the practicalities of harvesting has prompted recent investigations to focus on using *Eucalyptus* as a single stem biomass crop, grown on longer rotations than short-rotation coppice.

A recent privately funded programme of eucalypt research in Britain concentrating on single stemmed biomass crops has included material obtained from breeding programmes in Europe. AFOCEL (Association Forêt-Cellulose) began research into eucalypts as energy and pulpwood crops for south-west France as early as 1968 (AFOCEL 1982 in Purse and Richardson 2001). This produced elite clones of

E. gunnii and *E. gunnii* x *dalrympleana* hybrids. The programme was abandoned in 1985 due to losses of the first commercial plantings in 1984 due to cold. However, demand for *Eucalyptus* pulpwood initiated a new programme in 1995, focussed on planting on set-aside arable land (Terraux 2000 in Purse and Richardson 2001). Material from the French programme (*E. nitens* seedlings raised from Chilean seed and *E. gunnii* from Tasmanian seed) was established from May to August in 2001 across six sites covering Hants, Kent, Norfolk and Nottinghamshire (Purse and Richardson 2001). Intensive silviculture applied to *E. nitens* using directed fertilser application and rigorous weeding has allowed trees planted in May 2001 to have achieved a maximum height of 5.7m by December 2002 (Purse pers. comm. 2003).

Conclusion

There is compelling evidence that shows that certain eucalypts, particularly *E. gunnii,* will survive and grow rapidly in the British climate. If grown as a single stemmed biomass crop on longer rotations than short-rotation coppice, growth rates can be impressive and the problem of damage by silver leaf disease becomes irrelevant. Given the shortcomings of poplar and willow as fuel for co-firing in power stations it is time to re-examine the role of *Eucalyptus* as a biomass crop for lowland Britain.

The promising results from the Thetford trial highlight the importance of the trials established by the Forestry Commission in the early 1980s, through providing long-term information on survival, wood density and yields of cold resistant eucalypts. Given the recent interest in wood as a renewable fuel a systematic evaluation of the larger replicated trials is warranted.

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