Elsevier Editorial System(tm) for Applied Energy
Manuscript Draft

Manuscript Number: APEN-D-10-01239R1

Title: The potential for Eucalyptus as a wood fuel in Great Britain.

Article Type: Review Article

Keywords: Eucalyptus; Eucalyptus gunnii; Eucalyptus nitens; Great Britain; biomass; short rotation forestry

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Abstract: Considerable potential exists in the UK for utilising woody biomass, grown under short rotation forestry management systems, to produce electricity or heat. There are benefits to using biomass in generating heat and power the main environmental benefit being from substituting for fossil fuel combustion and consequent carbon emissions. Woody biomass production in short rotation forestry involves growing single stemmed trees rather than coppice over rotations of between 10 and 15 years. Eucalypts are particularly suited to such biomass production as they exhibit relatively high wood density, have suitable chemical characteristics, exhibit low moisture content and can be easily harvested all year around using conventional machinery if single-stemmed growth form is maintained.

The UK has a climate that is not well suited to the majority of eucalypts. However, there is a small number of eucalypt species that can withstand the stresses caused by frozen ground and desiccating winds or sub-zero temperatures that can occur. These species are from more southern latitudes and high altitude areas of Australia. However, even the most cold resistant species can be damaged by UK winter climate extremes and therefore careful matching of species to site environmental constraints is critical. Informed decision making is made problematic by the small area and limited distribution of current planting, although it is clear that particularly cold areas and for most species, sites with poor drainage should be generally avoided. This article provides a discussion of the potential of, and constraints to, using eucalypts for biomass in the UK and provides a tentative list of recommended species, their potential growth rates and their advantages and disadvantages.

The potential for Eucalyptus as a wood fuel in the UK.

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Manuscript of 16 June 2011

Introduction

In order to reduce greenhouse gas emissions and improve energy security the UK Government has made a commitment to source fifteen percent of the country's energy from renewable sources by 2020 [1]. The lead scenario in the UK renewable energy strategy suggests that 30% of electricity and 12% of heat could be provided through use of renewable sources of energy. Woody biomass is predicted to provide about 2% of the electricity generated in the UK by 2020 [1], but it is through the provision of heat that wood fuel is likely to have the greatest impact [2].

Thinnings and fellings from present sources and from bringing neglected woodlands back into management is unlikely to provide sufficient wood fuel to support the Government's aims and the resource is dispersed with variable ease of access and quality. A complementary approach is to develop sources of woody biomass which aim to produce quality fuel and can established close to the biomass demand, reducing both transportation costs and fossil fuel consumption. Previously the focus on woody energy crops in the UK was directed at short rotation coppice (SRC) but the material produced is of low density, high bark content and high moisture content, making it a less than ideal fuel. [3]. A more recent development is short rotation forestry (SRF), where single stemmed trees are grown over a rotation of more than ten years, producing material of between 10 and 20 cm diameter at breast height (dbh) and able to be harvested using conventional forestry machinery [4]. A suite of species is under consideration for short rotation forestry. One genus that has attracted attention is *Eucalyptus* due to rapid early growth compared with other tree genera [5] and the potential to use singled coppice in subsequent rotations. However, only a few *Eucalyptus* species are sufficiently cold tolerant to survive and grow well in the UK. This article presents a review of the information on cold-tolerant eucalypts and highlights their potential for commercial cultivation in Great Britain and assesses the potential for using eucalypts as a woody biomass fuel source.

Eucalypts as a productive wood fuel resource

To be economic in producing wood fuel, a species should exhibit the following characteristics [3]:

- Produce (moderately) high density wood
- Have suitable chemical characteristics
- Produce wood that easily dries
- Be easily harvested
- Harvestable using conventional machinery
- Harvestable all year around

Eucalypts can largely meet these criteria: they have potential for high productivity over short rotations, they tolerate a wide range of soils and they commonly exhibit straight stem form in species utilised in production forestry. Furthermore, eucalypts, unlike many trees, do not have a true dormant period and retain foliage which enables growth during warm winter periods. The threshold for growth and photosynthesis in their native climate is around 8^{o}C [6], whilst general limitations of growth in the UK have been reported for *E.* gunni at 5^{o}C and 8^{o}C for *E. nitens* [4]. Eucalypts are one of the most productive plantation species, with temperate forestry reporting yields of 18 m^{3} ha^{-1} year^{-1} over a twelve year rotation with single species clones [7] and up to 35 m^{3} ha^{-1} year^{-1} with hybrid clones [8], in France. Estimates of mean annual increment (stem growth rate) vary with site (soil, climate and biotic influences) and genetic (species and origin) factors. Generally there is a trade off between cold hardiness and growth rates, and also the most cold tolerant species tend to have poor form, which although less important for biomass than for sawn timber will still influence the cost of harvesting, transport and processing. The slower growing, but more cold-tolerant species like *E. gunnii* have yielded mean annual increments of around 10-15 m^3 ha^{-1} yr^{-1} on a 10-12 year rotation across a series of trials in the UK [9] with one report of 25 m^3 ha^{-1} yr^{-1} at 11 years old [10]. Faster growing species such as *E. nitens* may yield mean annual increments of over 25 m^3 ha^{-1} yr^{-1} [11]. A comparison of the growth rates and rotations of tree species commonly used in production forestry in Great Britain plus those estimated for eucalypts are given in Table 1.

TABLE 1 HERE

Wood density is also important as it largely determines the calorific value per unit volume [11] and eucalypts have denser wood than other species utilised for biomass production over short rotations: SRC willow has a wood density of 0.4 Mg/m^3 [13], whereas *E. nitens* grown in Australia on two sites had a density of 0.471 Mg/m^3 and 0.541 Mg/m^3 [14] and *E. gunnii* grown in the Midi Pyrenees in France, a density of 0.5 Mg/m^3 [7]

Eucalypts for short rotation forestry based on current knowledge

The lack of widespread plantings of a range of eucalypt species in the UK makes it difficult to identify species potential across varied site types. However, several sources of information are available to attempt a preliminary characterisation of their biomass potential in relation, particularly, to their cold tolerance. In addition to Evans' [15] findings anecdotal guidance on climatic tolerances, comes from Eucalyptus Nurseries [16], Eucalyptus Passion [17] and Primabio [18]. These findings plus notes from Purse [19, 20, 21] and personal observations have been used to compile Table 2. Neilan and Thompson [11] have produced a review of the findings from trials in the Republic of Ireland, but some of their findings are applicable only to those parts of the UK with a comparable (mild) climate. The compilation of information presented in Table 2 has focused on species that have rapid growth and achieve dimensions appropriate for wood fuel in northern temperate forestry. We categorise species by the minimum winter temperatures that they can survive, after hardening, but unseasonal frosts must be considered as they pose a particular risk. Some species have been omitted due to slow growth and/or poor stem form, including *E. pauciflora* and *Eucalyptus perriniana*.

TABLE 2 HERE

Booth and Pryor [31] describe the climatic requirements of 22 eucalypt species suitable for plantation forestry, six of which can be considered cold-tolerant. Comparing the requirements with the climate of Britain, it is clear that two main constraints exist to planting eucalypts widely; the most important is low temperature and a secondary consideration is adequate soil moisture. Additionally, the importance of such constraints is likely to change in the future as a result of climate change. Evans [5] recommends caution when using generalised measures such as minimum temperature data to assess site suitability. He asserts that it is rapid cooling following warm periods that presents the main danger to eucalypts. This is supported by the work of Davidson and Reid [36] who have shown that unhardened eucalypts can be killed by relatively mild frosts. In addition Purse and Richardson [10] note that the most damaging situations arise when polar air masses are over the UK, as the resultant prolonged severe cold is capable of killing even hardened, mature eucalypts. The more common occurrence of radiation frosts tend to kill only unhardened, young trees and affect air temperature close to ground level more. Work linking metabolic activity to temperature of eucalypts by Anekonda *et al* [37] also supports the assertion that, in general, using latitude and altitude and broad climatic characters is useful in matching exotic species or origins to site. However, the authors also note that this does not characterise a climate sufficiently and that temperature fluctuations on a monthly or daily time scale are also important and a more sophisticated approach is needed. Even in areas that are sufficiently warm, care should be taken to avoid frost hollows and soils that are waterlogged, as this reduces the resistance of some eucalypts to frost. A further factor determining the influence of climate is the origin of the planting material used with variation observed in cold tolerance between and within provenances of species such as *E. gunnii* [15; 25] and *E. nitens* [15, 33].

There are opportunities for the development of hybrid clones as they can provide a more favourable mix of traits than each parent alone [38] and may offer potential for boosting productivity. Eucalypts suited to the UK climate, such as *E. gunnii* have been shown to hybridise readily, with most success being with closely related species [39]. For *E. gunnii,* species capable of hybridisation include *E. nitens*, *E. dalrympleana* and *E. viminalis*. Evans [5] suggests that a hybrid of *E. gunnii* and *E. nitens* might be particularly suited to the needs of British forestry, combining good form, fast growth and cold-tolerance. However, experience has shown that obtaining rootable hybrids from these parents is challenging. Hybrid clones of *E.gunnii* x *E. dalrympleana* in France showed excellent growth of around 35 m^3 ha^{-1} $year^{-1}$ at age eight years and continued to grow rapidly thereafter [11]. However, planting of these hybrids in France ceased due to high mortality following an exceptionally severe frost of -21°C in 1985 [8] but trials have started again [40]. Experience with eucalypt hybrids has shown that crosses do not exhibit hybrid vigour, with F1 offspring tending to show characteristics intermediate with those of their parents [41]. While this can allow attractive aspects of two species to be combined, single species clones might also have potential. For example, clones of particularly cold-tolerant individuals of *E. gunnii* may extend the suitability of this species to colder locations as individuals have been reported to survive temperatures of below –19°C [15].

Under future climate scenarios temperatures are predicted to rise across the country with increases of between 1.5 to 3°C in winter and a higher rise of between 2.5 and more than 4.5°C in summer for a medium-high emissions scenario by the 2080s. Rises in temperature will generally be greatest in the South East and least in the North West [42]. While higher overall temperatures should favour the planting of eucalypts, other factors, such as enhanced atmospheric carbon dioxide levels may increase the risk of frost damage in evergreens like eucalypts [43] and this has been shown in experiments with *E. pauciflora* [44]. This observation is supported by other studies, which have shown that increased atmospheric CO_2 delays acclimation in autumn (Coreys et al. 2006 in [42]) and accelerates the loss of cold-hardiness in spring [42]. In addition to periods of winter cold, unseasonal frosts can be particularly damaging. Booth and Pryor [31] note that autumn frosts are likely to be the most damaging type of frosts for eucalypts grown in the UK and damage in these circumstances is also likely to increase with elevated levels of atmospheric CO_2.

The limitation of cold is illustrated through an examination of the climatic conditions suitable for *E. gunnii,* a very cold tolerant species and *E. nitens*, one which is less so; *E. gunnii* is known to withstand freezing temperatures of down to -18°C and *E. nitens* of -12°C [45, 31]. If the extent of areas in Britain that experience -18°C and -12°C minimum temperatures are examined on maps showing 40 year climatic averages from 1960-1999 [46], it is only coastal areas in Britain where absolute minimum temperature did not fall below -12°C. During the same forty year period considerable areas in eastern Scotland and in southern central England exhibit absolute minimum temperatures of below -18^{o}C. This highlight that there are considerably greater risks from damage by cold in planting *E. nitens* than *E. gunnii*. Predictions of climate change developed by the UKCIP02 [42] for a scenario of medium-high emissions show a rise of up to 3^{o}C in mean winter temperatures and greater increase in summer. Increases in maximum temperatures during summer in southern England may be as high as 5^{o}C in a medium emissions scenario [42]. Provided sufficient soil moisture is available, more extensive areas of Britain should become suited to growing eucalypts. Figure 1 illustrates changes in accumulated temperature at the threshold temperature above 5^{o}C (AT5) generated with the Ecological Site Classification system (ESC) using UKCIP02 climate change projections for 2050 low emission scenarios.

FIGURE 1 HERE

A further climatic constraint to planting eucalypts is available soil moisture. *E. gunnii* is adapted to temperate climates with mean annual rainfall of 800-2400 mm and *E. nitens* of 750-1500 mm [31]. Long term mean annual rainfall of less than 750 mm is experienced over much of eastern England [48] with warm temperatures this results in high soil moisture deficits, which may limit growth. Recent predictions of climate change [42] show that while overall mean annual rainfall will stay relatively constant a variation in seasonal precipitation is predicted: in summer, during the growing season rainfall will be reduced, while winter rainfall will increase. This summer rainfall reduction is projected to be particularly pronounced in the south east of the England, with this region only receiving around 40% to 50% of current rainfall by the 2080s for the high emissions scenario or 60 to 80% under the low emissions scenario [42]. Increased summer temperatures coupled with a reduction in rainfall will lead to greater moisture deficits. Figure 2, generated through ESC using UKCIP02 climate projections shows predicted future moisture deficit in 2050 across Great Britain for high and low emissions scenarios. Yields are likely to be slightly reduced by climate change in these drier areas and caution is warranted regarding planting *Eucalyptus* on freely draining soils with low moisture retaining capacity.

FIGURE 2 HERE

Using ESC, provisional areas have been identified that are suitable for planting in Britain with another frost-sensitive, southern tree, *Nothofagus nervosa* This has been achieved by defining suitable areas from accumulated temperature and moisture deficit data. Areas in Britain with a minimum temperature of -16^{o}C every 50 years were rejected as being unsuitable due to the risk of failure due to cold [4]. These areas have been identified using work undertaken by Murray, Cannell and Sheppard [49] on incidence and severity of frost in Britain And it would be worthehil taking a similar approach to eucalypts.

Impact on the environment

With interest in eucalypt planting rising, there has been increasing concern regarding potential negative environmental impacts. In 1985 a literature review detailed evidence of impacts by eucalypt plantations on water supply, erosion, availability of nutrients, competition with other vegetation and displacement of ecosystems [50]. However, these impacts related to specific cases and no generalisations could be made. In France, over 1000 ha of generally small-sized plantations have been established in the Mid-Pyrenees of species that are similar to those suited to the climate of Britain [51]. While water use was a concern raised in France, eucalypts use water efficiently but consume more water than some tree species due to their higher productivity. Concerns about adverse environmental effects of SRF, including eucalypts, led to a further study focused on the UK [4]. The study gathered expert opinion and predicted the impacts of SRF with different species and in comparison with other land use, such as pasture, arable cropping and SRC. It was concluded that guidelines should be followed to avoid adverse impacts on soils, hydrology, biodiversity or increase the damage by pests and diseases caused by SRF [4].

Of the two eucalypts examined in the study, *E. nitens* was considered to have greater potential negative impacts on the environment than *E. gunnii*, particularly in aspects such as biodiversity and hydrology. This is because *E. nitens* has certain characteristics; the dense shade of its canopy, the slower rate of decomposition of its leaf litter and its fast growth and high water requirements [4]. However, Hardcastle [4] concluded that more widespread planting of eucalypts should be considered, provided certain restrictions be put in place to minimise environmental impacts and that monitoring of activities be carried out by the relevant body.

Socio-political and economic factors

Policy developments directed at energy and land use, including forestry, can influence the uptake of SRF in the UK. Current land use strategy has largely been determined by the policy set by the UK Government and the European Union. To date uptake has been slow, one factor being that SRF does not meet the requirements of Forestry Commission woodland grants nor does it use species that attract grant support under the Energy Crops Scheme. A recent change likely to promote short rotation forestry has arisen from a consultation undertaken by DECC (Department for Energy and Climate Change) in late 2008, for England and Wales, which proposed dedicated biomass crops should attract additional payments [52]. An incentive now supports power generation from biomass crops, including woody ones such as SRF. Recently, it was announced that heat generated from renewable energy would also attract support by 2011, through the Renewable Heat Incentive (RHI) [53].

The Woodfuel Strategy for England is aimed at improving the management of the 60% of woodland that is neglected in order to provide a supply of forest biomass [2]. In Scotland, a study investigating supply of wood fuel recommended, amongst other things, that trials of short rotation forestry be a priority activity [52]. The impacts of short rotation forestry on soils and hydrology, and net site carbon benefit are being assessed in a series of research and demonstration trials of several species, established in 2009 by Forest Research, in both Scotland and England [53].

Compared with other land uses, biomass forestry has two main attractions in terms of reducing greenhouse gases [56]. Firstly, it requires low fossil fuel-derived inputs, such as inorganic fertilisers, pesticides and fuel for farm machinery. Secondly, the wood grown under SRF provides a substitute source of energy replacing fossil fuels which, with sustainably managed afforestation, could reduce atmospheric CO_2. An additional potential benefit of a change from arable crop production to plantation is increased soil carbon storage. Vanguelova & Pitman [57] identified that "soil carbon sequestration by SRF is highest on arable soils previously having very low soil carbon….(whilst) impact of SRF on the higher carbon stocks of grassland soils is less certain, although any reductions are likely to be outweighed by the carbon gain in woody biomass". Matthews and Broadmeadow [58] presented different woodland management scenarios and modelled direct and indirect substitution and carbon sequestration in trees and soil. The amount of CO_2 saved through substitution of fossil fuels was calculated in comparison with a "business as usual" scenario, based on current energy use. Matthews and Broadmeadow [58] identified that fast growing woody biomass crops on short rotations, such as eucalypt SRF are an attractive option, especially their relatively low cost of emissions abatement and the short term benefits they yield. It is important to acknowledge the limitations of these analyses: reliable data is available for CO_2 balance of conventional forestry, but there is little or no evidence for hardwoods, including eucalypts, under SRF management in the UK. Kerr [59] lists four areas that make estimating yields imprecise: the shorter rotations, the potential for using 'novel' tree species, the intensive silvicultural approach and the type of sites that would be planted under short rotation forestry. Therefore modelled estimates need to be considered as being preliminary, which highlights the need for more underpinning information. The current 'best estimates' are from Kerr [59], using published data, which show that over a ten year rotation, yields of 1.5 to 8.2 odt ha^{-1} y^{-1} are possible from *E. gunnii* and 2.5 to 7.6 odt ha^{-1} y^{-1} from *E. glaucescens*.

Conclusions

The interest in using biomass as a source of energy has provided a catalyst for the re-examination of the potential role of eucalypts in short rotation forestry in Britain. Their high productivity can provide substantial yields of biomass, reduce greenhouse gas emissions from fossil fuel consumption and can also reduce operational fossil fuel use by replacement of more energy intensive forms of land use. Existing trials and small plantations of eucalypts have shown that there are a limited range of species of eucalypts that can survive and thrive in the relatively low temperatures prevalent in the UK. The limited distribution and extent of plantings make detailed matching of species to site currently imperfect. A sensible approach is, therefore, to attempt to identify species and provenances that will perform well over a wide range of sites and avoid areas that are particularly cold, have low rainfall and for most species, have poor drainage.

Acknowledgements

The authors would like to thank the University of Cumbria for providing funding to Andrew Leslie and John Purse of Primabio for providing a considerable amount of information on the performance of eucalypts in the UK. The maps of accumulated temperature and moisture deficit were provided by Michal Petr (GIS Analyst at Forest Research) and the authors would like to thank him and Duncan Ray (Forest Research), for their assistance. Finally the authors would like to acknowledge the constructive comments provided by James Morison and Robert Matthews of Forest Research and the two journal referees, Dr Christine Cahalan of Bangor University and Dr Frits Mohren of Wageningen Agricultural University.

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Figure 1: Maps of baseline accumulated temperature and projections to 2050 under low and high greenhouse gas emissions based on UKCIP02 predictions [47]

Figure 2: Maps of baseline moisture deficit and projections to 2050 under low and high greenhouse gas emissions based on UKCIP02 predictions [47]

Figure

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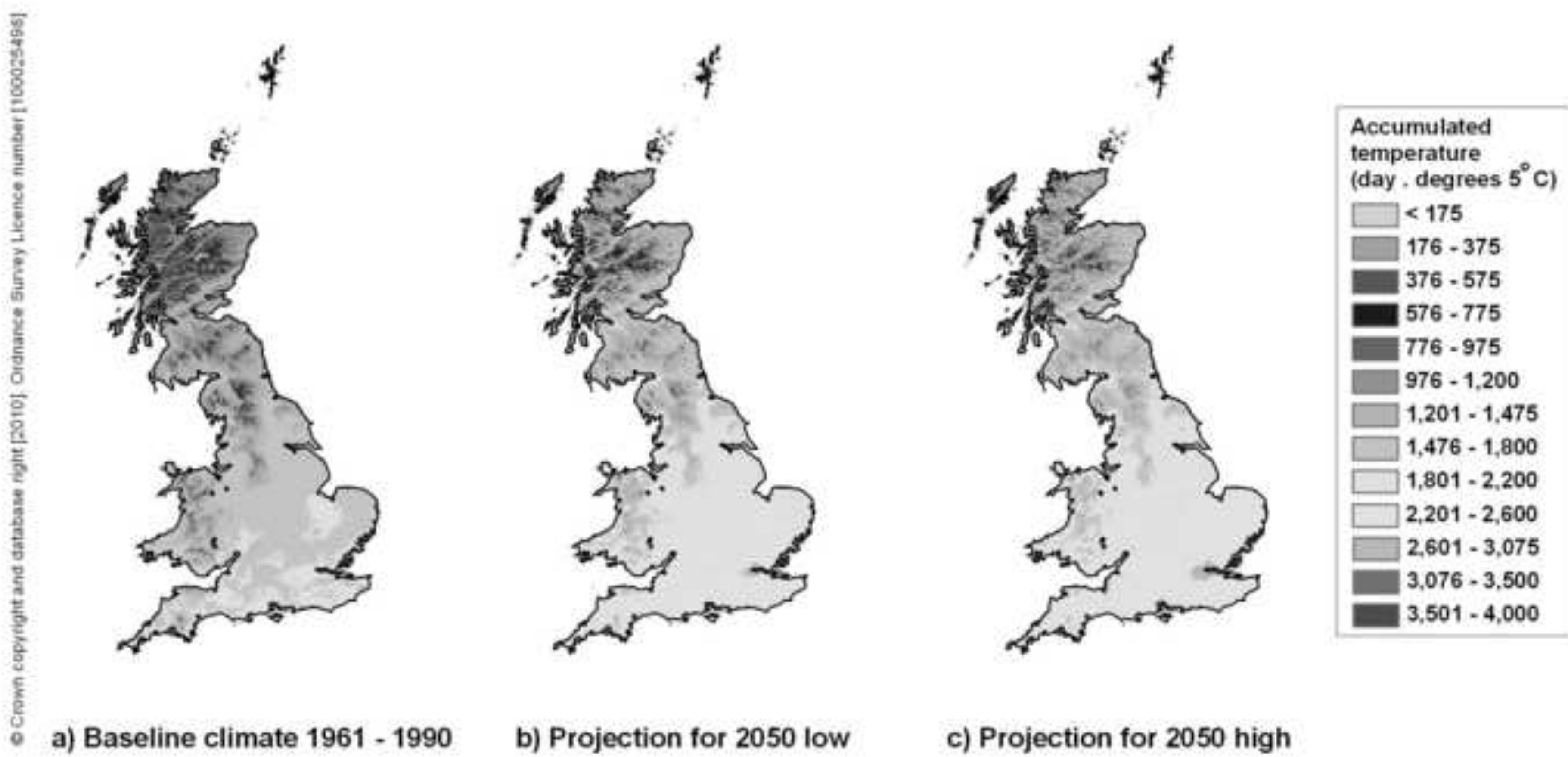

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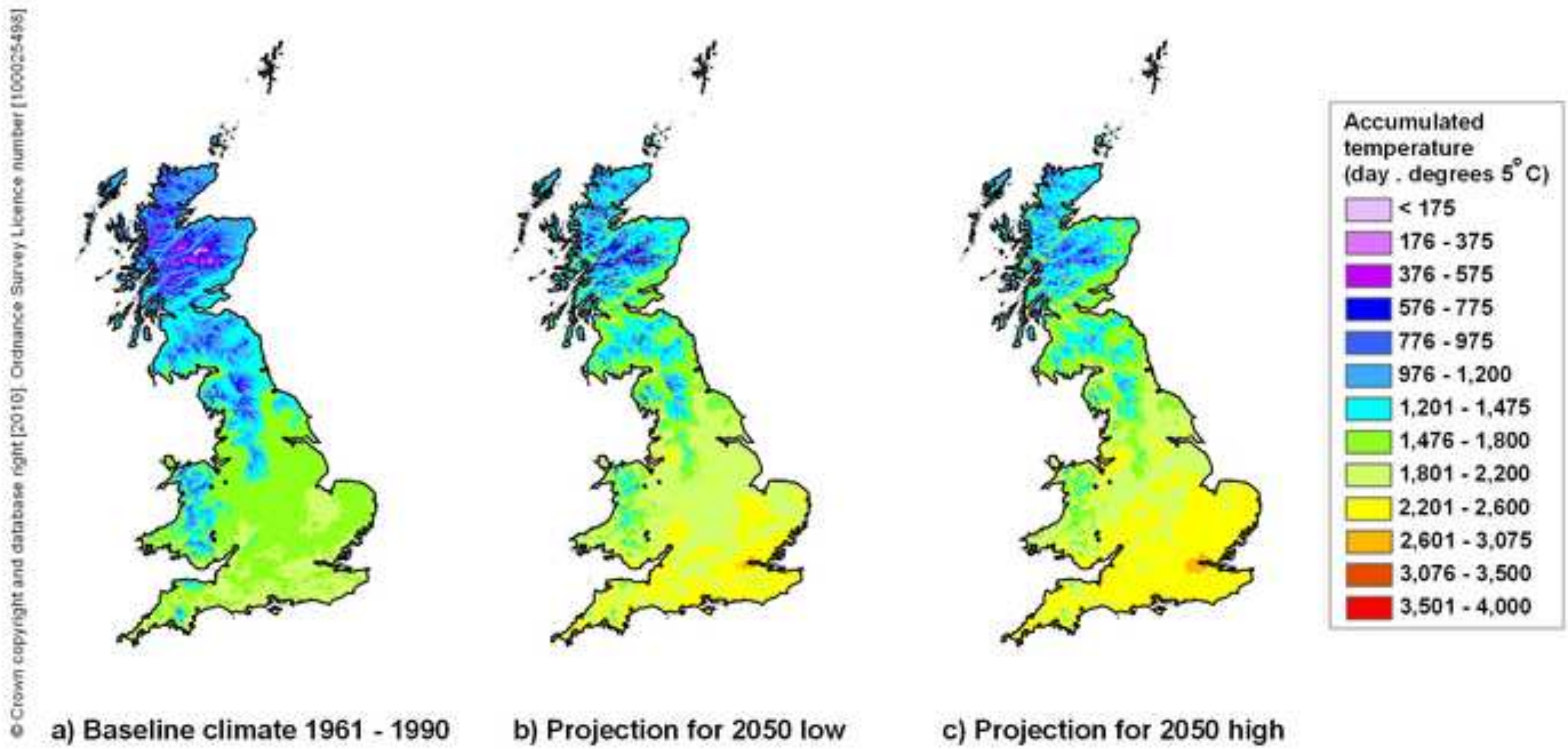

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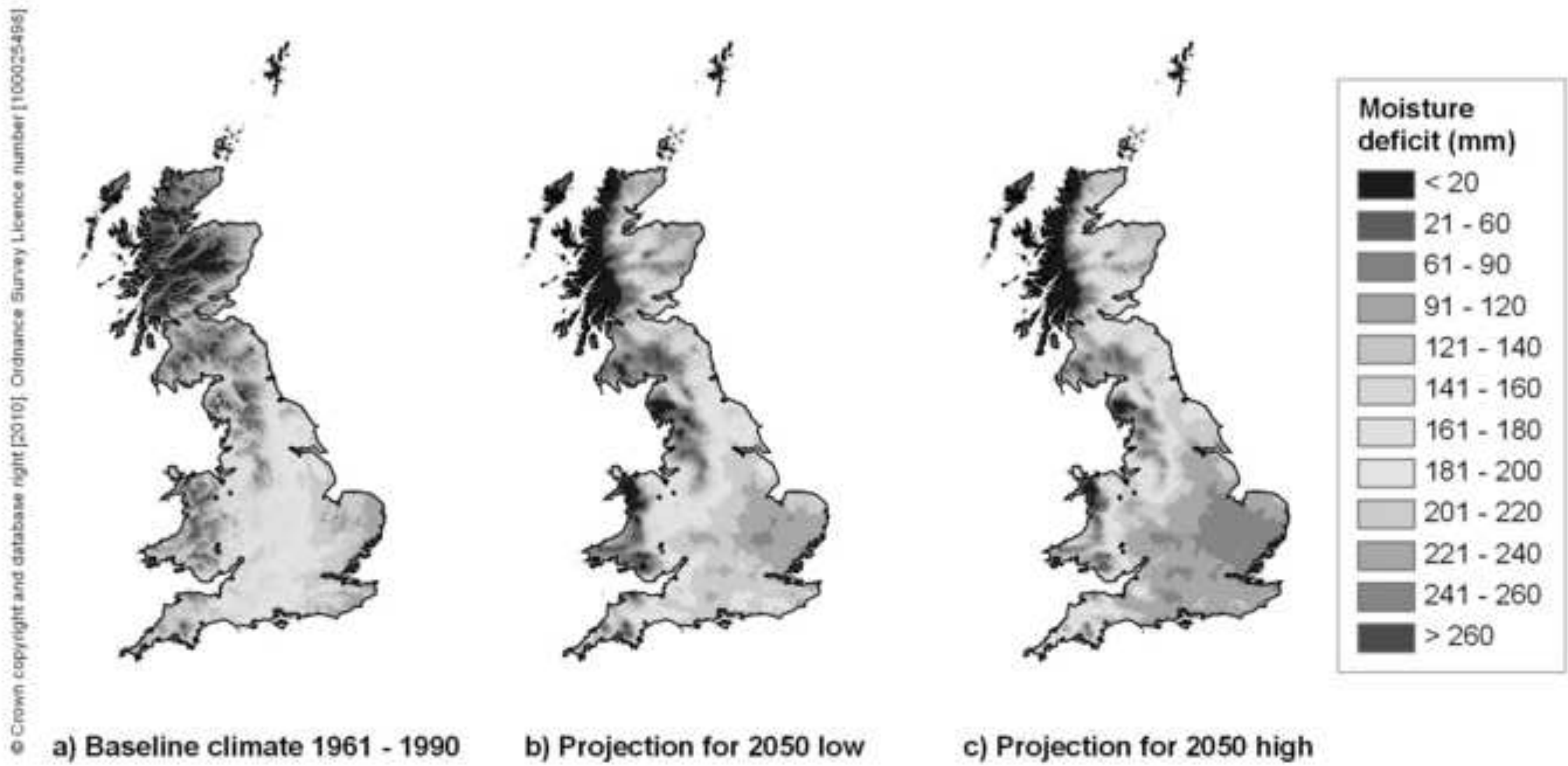

a) Baseline climate 1961 - 1990 b) Projection for 2050 low c) Projection for 2050 high

Figure

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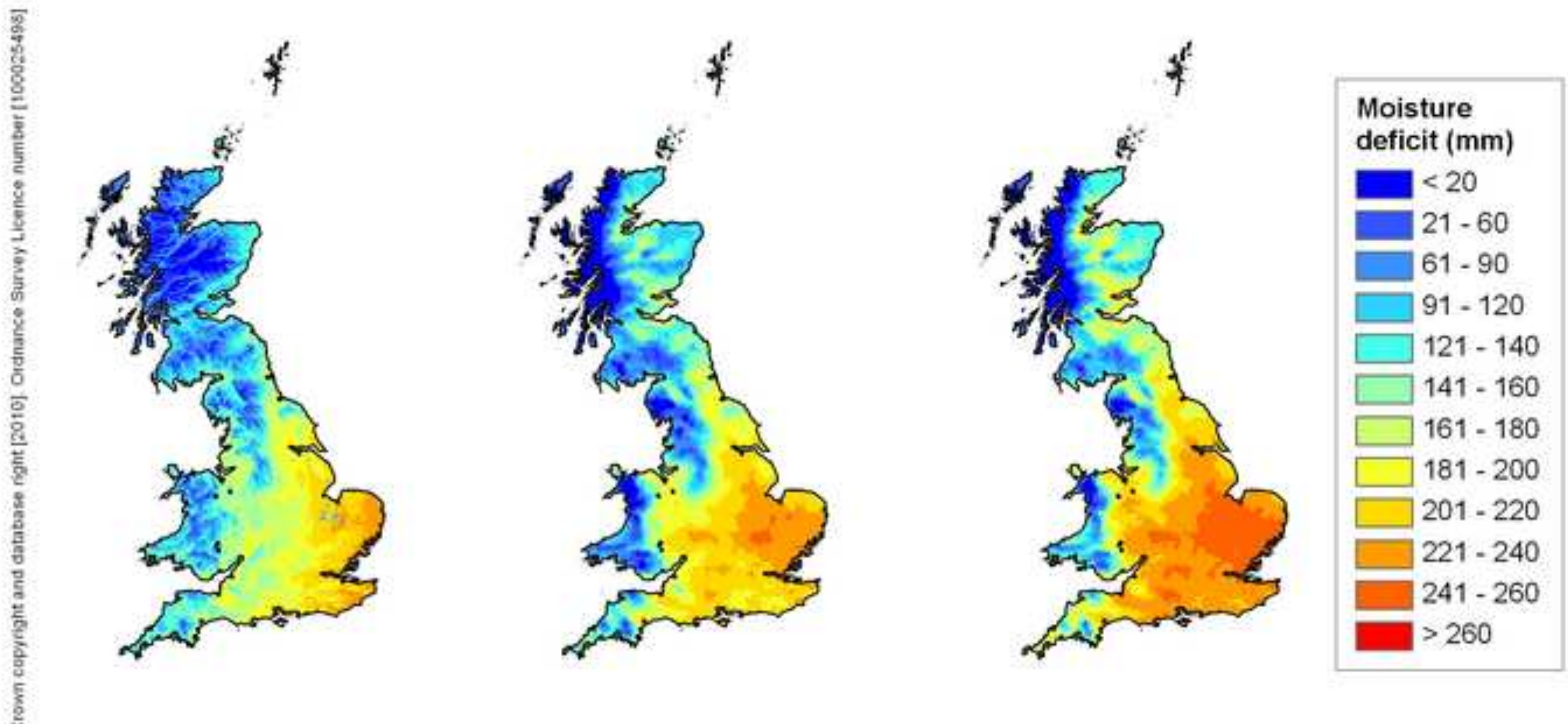

a) Baseline climate 1961 - 1990 b) Projection for 2050 low c) Projection for 2050 high

Table

Table 1 Growth rates and rotations of trees when used in production forestry in Great Britain [12] with estimates of growth of *E. gunnii* and *E. nitens*[4] converted from oven dry tonnes to m^3 using a density of 0.5 tonnes per m^3.

Tree species	**Potential yield (m^3/ha/yr)**	**Average yield (m^3/ha/yr)**	**Rotation (years)**
Scots pine (*Pinus sylvestris*)	4-14	9	55-76
Corsican pine (*Pinus nigra* var *maritima*)	6-20	13	45-60
Lodgepole pine (*Pinus contorta*)	4-14	7	50-60
Japanese larch (*Larix kaempferi*)	4-16	9	45-55
Douglas fir (*Pseudotsuga taxifolia*)	8-24	14	45-60
Norway spruce (Picea abies)	6-22	12	50-70
Sitka spruce (*Picea sitchensis*)	6-24	13	40-60
Oak (*Quercus robur*/ *Quercus petraea*)	2-8	5	120-160
Beech (*Fagus sylvatica*)	4-10	6	100-130
Ash (*Fraxinus excelsior*)	4-10	5	60-80
Birch (*Betula pendula*/ *Betula pubescens*)	2-10	5	40-60
Eucalyptus gunnii		18	12
Eucalyptus nitens		30	8

Table 2 The potential and constraints of the eucalypt species showing potential for biomass production under UK conditions. All species are categorised by their hardiness to cold events. (hardiness based on [22])

Very hardy – likely to survive long periods of –10 to –14°C and short periods of –18°C

Species	**Growth rate & form/ Max height**	**Potential**	**Disadvantages**

E. gunnii	Fast - 1.5 – 2m height growth per year [22] and above $15m^3ha^{-1}\ y^{-1}$[9] Wide range of growth forms [23, 24] means careful selection of material is necessary. Select forest tree forms and avoid shrubby sub species such as *E. gunnii* ssp *archeri*	One of the most frost tolerant eucalypts, can be established over a wider range of sites than others being suited to sites where Yield Class 10-14 m^3/ha/yr conifers can be grown. Provenances that can tolerate the climate of colder areas of Britain have been identified, such as those from Lake McKenzie in central Tasmania [17,25] and observations show no decline in growth rates with frost tolerance between provenances [15]. Resistant to waterlogged soils in its natural habitat. Considerable variation in the phenotype of different provenances and sub-species (which is reflected in their frost tolerance [26, 17, 25]). Some stands show good form, such as the one planted in 1966 at Glenbranter and form could be improved through selection of provenance and superior individuals. It will coppice successfully and has been used in short rotation coppice trials where productivity was high [27, 28]. A light crowned species, allows light to penetrate to the forest floor and results in less impact on ground flora [4]	Poor form of many trees, could make transport and processing more costly as a source of biomass. A further disadvantage for this use is a wood that is less dense than some species [11]. Also high moisture content of wood means that it needs a long period of drying of one year for firewood [22]. Evans [15] stated that it could have potential for pulp but unpredictable grain makes the wood unsuitable for timber. Unlike most eucalypts the leaves are palatable to deer, rabbits and hares and so it is susceptible to browsing [12, 19]

<u>Hardy</u> – as above but unlikely to survive periods of colder than -16^{o}C

Species	**Growth rate & form/ Max height**	**Potential**	**Disadvantages**
E. glaucescens	Fast - 1.5 – 2m height growth per year [22]	More cold tolerant then *E. nitens* and almost as resistant to frost as *E. gunnii*. Considerable potential for production forestry showing excellent stem form. Observations of block planting at the New Forest showed faster growth than *E. gunnii* and excellent self pruning, characteristics which could make it a timber species [21] Found to be highly unpalatable to deer in a planting in West Sussex in 2007 [19, 21]	Evans [15] noted that only one origin exhibited sufficient cold tolerance in the Forestry Commission trials to be planted more widely.

<u>Moderately hardy</u> – likely to survive long periods of -6 to -9^{o}C and short ones of $- 14^{o}$C

Species	Growth rate & form/ Max height	Potential	Disadvantages
E. coccifera	Moderate to fast - 1.0 – 2m height growth per year [22]. A recent assessment of a trial at Exeter of trees 29 years old gave a mean annual increment of $9m^3 ha^{-1} y^{-1}$ [unpubl. data]	Observations by Purse (20) of trials at Thetford, Glenbranter and an older planting attributed to *Eucalyptus nitida* but probably *E. coccifera* at Bishop's Wood, Truro show promising growth and good stem form.	Slower growing than other species at a trial at Exeter [unpubl. data]
E. dalrympleana	Fast - 1.5 – 2m height growth per year [22]	A close relative of *E. gunnii* which is more frost tolerant than *E. nitens* and exhibits faster growth and better form than *E.gunnii*. occupies a wide range of altitude [29] Considered suited to alkaline soils [11], and observed growing well on brown earths overlaying limestone pavement at Dalton, Cumbria. Gundal hybrid clones (*E. gunnii* X *E. dalrympleana*) produced in France showed promise, having better form and being less palatable than *E. gunnii* but more cold tolerant than *E. dalrympleana* [8]	Self pruning and vigorous when coppiced [11] Gundal clones proved to be less hardy than *E. gunnii* and were abandoned from planting programmes in France [8].
E. delegatensis	Moderate to fast - 1.0 – 2m height growth per year [22]. Growth at a trial at Exeter at 29 years old averaged $11m^3 ha^{-1} y^{-1}$ with one origin exceeding $30m^3$/ha/y [unpubl. data]	An important source of wood in Australia for construction timber and pulp [30]. Good growth but poorer survival in more southerly Forestry Commission trials in Britain [21] and at a small trial in Cumbria. Exhibits promising growth and survival in the milder climate of Southern Ireland, being faster growing than some origins of *E. gunnii* in a planting at Bree [11]. Found at a wide range of altitudes [29]. Evans [15] recommends high altitude provenances from New South Wales.	Some provenances do not coppice and has a relatively low wood density, which makes it less suited as a species for biomass production [11]
E. urnigera	Fast - 1.5 – 2m height growth per year [22]	Another close relative to *E. gunnii* and similar in its tolerances [22]. However, it has the advantage of being less palatable than *E. gunnii* and often displaying better form. Some trees of this species planted in the UK would appear to be natural hybrids with *E. gunnii* [19]. Considered by Neilan and Thompson [11] as one of three species with particular potential across a range of sites in Ireland.	Lower productivity than some other eucalypts [11]

Less hardy – likely to survive long cold periods of less than –6°C and shorter ones down to –9°C

Species	Growth rate & form/ Max height	Potential	Disadvantages
E. johnstonii	Fast - 1.5 – 2m height growth per year [22].	*E. johnstonii* has shown encouraging growth and survival across a variety of sites in Ireland [11] Coppices vigorous but not particularly fast growing as a single-stemmed tree, although exhibits good stem form. Some seed origins seem hardier than *E.nitens* or *E. delegatensis*, being similar to *E. gunnii* and *E. pauciflora* [5], which could make this a suitable species for biomass in Great Britain.	Poor survival of most origins of *E. johnstonii* at a trial at Exeter after 29 years [unpubl. data]
E. subcrenulata	Fast – 1.5-2m height growth per year [22]. Estimated growth of $14m^3ha^{-1}yr^{-1}$ over 29 years at a trial at Exeter [unpubl. data]	Evans [15] described central or southern Tasmanian origins of this species as having the greatest potential for growing high quality timber in the British Isles. Survival of 68% and excellent growth and stem form at a trial at Exeter [unpubl. data].	Planting should be restricted to warmer, western parts of Britain.
E. nitens	Very fast - over 2m height growth per year [22] and potentially over $30m^3ha^{-1}yr^{-1}$ [10]	Not particularly frost tolerant, but possibly a "moderately hardy" species, surviving down to -14°C [31] or -12°C [11]. There are differences in frost resistance between provenances and those from higher altitude areas in Victoria seem best adapted to the British climate [15] and careful matching of this species to site is crucial. It has failed completely in several Forestry Commission trials, such as at Thetford [31] and in one in Ireland in 2000 [11]. Considerable variation in frost tolerance by provenance and individuals within provenance [33]. Fast growing, with those at Kilmun Arboretum being possibly the fastest growing tree in Britain [5]. Widely planted in countries other than Great Britain, so its silviculture is well-understood. If pruned it can provide sawn timber.	Dense crowns shade out ground vegetation which reduced impact of rain and binds soil, so may not be appropriate under certain circumstances, such as where there is potential for soil erosion. Does not coppice very successfully and known as a shy flower producer, which can make seed supply problematic. A closely related species, *Eucalyptus denticulata* formerly known as the Errinundra provenance of *E. nitens* may have potential, as although slower growing [34] it coppices [35].