Recent results of growing *Eucalyptus* in Ireland

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Abstract
Interest in growing *Eucalyptus* in Ireland has increased in the last 10 years as a result of the increased demand for biomass and the projected shortages of fibre and fuel in the near future. As one of the fastest growing of the tree genera, *Eucalyptus* has the potential to supply some of these demands. Nevertheless there are a significant number of unknowns regarding the growing of *Eucalyptus*. This paper summarises the knowledge accumulated to date for this genus, as it relates to conditions in Ireland.

Keywords: *Short rotation forestry, biomass, bioenergy, fibre, panel boards, cold hardiness.*

Introduction
The current forest biomass requirements for energy on the island of Ireland have reached a level where demand exceeds supply and this gap has been forecast to increase (Phillips, 2011). It is generally accepted that this gap will not be filled from conventional forestry sources. A very fast growing, short rotation tree species is needed and some species of the genus *Eucalyptus* appear to be able to fill this need.

Although early plantings of *Eucalyptus* species in Ireland date from the mid 19th century, and despite the fact that trials of a number of species have been established for over 100 years, there is still a great deal that remains unknown about the genus and how best to grow and manage it under Irish conditions. Mooney (1960) summarised the situation in the early 1960s, which was later updated by Neilan and Thompson (2008). However, since 2008 experience in growing and utilising *Eucalyptus* material in Ireland has increased. The purpose of this paper is to summarise the results achieved, to point out the gaps in current knowledge and to highlight the potential of *Eucalyptus* as a short rotation species for Ireland.

Historical background
The rapid growth and wide variety of species (over 800) found within the genus *Eucalyptus* has attracted interest among foresters around the world since they were "discovered" in 1774. The first introductions of *Eucalyptus* species to Europe took place in the early 19th century. Most of the early material was planted in gardens and arboreta in Ireland with mixed results. One of the early surveys carried out by Elwes and Henry (1912) summarised results up to that date with the statement "If one may judge from the numerous references in horticultural literature to this genus, none has

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been more persistently tried in various parts of the country; and yet when we come to record the small number of trees which have endured our climate for more than a few years, it must be acknowledged that none has proved more disappointing." In spite of this dismal record these authors went on to discuss the performance of 12 species in the British Isles! Later Fitzpatrick (1932) listed 13 species that had grown well in Ireland. Martin (1948) summarised the survival of a range of species in the British Isles, including results from Mount Usher, Co. Wicklow, Rostrevor, Co. Down, Brook Hall, Co. Derry and Glasnevin, Co. Dublin.

Regarding its use in forestry, A.C. Forbes, who established the first experimental forestry plots of *Eucalyptus* at Avondale in 1908, concluded that *E. urnigera* (Hook. f.), *E. viminalis* (Labill), *E. muelleri* (T.B. Moore) and *E. gigantea* (name later changed to *E. delagatensis* (T.T. Bak.)) were the most promising species (Forbes, 1933). The results of a series of three species trials planted in Ballymanus property in Glenealy Forest between 1934 and 1937 have been summarised by Mooney (1960) and more recently in Neilan and Thompson (2008). These trials were later followed by a series of trial plots established throughout the country between 1925 and 1961, some of which survive today. Unfortunately much of the information about these trial plots and their performance has been lost and it is difficult to draw any clear conclusions from them.

The objective of these early trials was to produce material for sawn timber, board manufacture, pit props or transmission poles, none of which proved to be successful (Mooney 1960). Problems with splitting and cracking reduced interest in the genus and work with *Eucalyptus* essentially ended in the early 1960s. Since that time, however, *Eucalyptus* species have continued to be planted both as a landscape species as well as commercially for the production of foliage material for use in the cut flower market.

The potential for growing *Eucalyptus* in the UK has been summarised by Julian Evans in a series of papers published in the 1980s (Evans, 1980, 1983a, 1983b, and 1986). He concluded that several species (and specific provenances of some of these species) possess sufficient cold hardiness to survive in the UK. He suggested that some species should be able to produce fibre on upland sites in the UK of Yield Class 12 to 16 on a 10-year rotation. A more recent summary of UK interest in the genus is provided by Leslie et al. 2011.

In Ireland, a series of plots was established in 1993/94 of *E. nitens* ((Dean and Main.) Maid.) (not previously tested in Ireland), *E. gunnii* (Hook. f.) and *E. delagatensis*. The early results from these plots, discussed in Neilan and Thompson (2008), showed that while some of the species used earlier had good survival and growth, there were others that had a greater potential for volume production (Figure 1). While the original objective of these trials was timber production, interest has changed in recent years as a result of the unsurpassed growth rates of *Eucalyptus*. A new project began in 2008 within Coillte to "assess the potential of growing *Eucalyptus* species (particularly *E. nitens*) in Ireland for the purpose of producing fibre for use in the manufacture of panel boards and possible biomass for energy" (unpublished internal Coillte report). The project has since been expanded to include both sawn timber production and the use of *Eucalyptus* species other than *E. nitens*.

Figure 1: *An 18-year-old stand of* Eucalyptus nitens *next to one of Sitka spruce, a year older, at Cappoquin, Co. Waterford.*

The establishment results described in this paper come from a series of operational trials testing a range of species on a series of different reforestation sites in the Coillte estate, established between 2008 and 2011. All trials were planted with 25 to 30 cm containerised plants, established at 2 by 2 m spacing. The objective was to keep establishment costs (including plant costs) as low as possible, while carrying out all necessary operations for the successful establishment of the crop.

In 2008, *E. nitens* and *E. globulus* Labill (25 cm, 4 to 5 months old) plants were imported from a nursery in Spain. During the winter of 2008/09, low temperatures (-7 °C) damaged or killed most of the *E. globulus* which highlighted the fact that this species is only suitable for planting in coastal sites where temperatures are unlikely to fall below this point. As a result, the project subsequently focused on planting only *E. nitens*, which perhaps in hindsight, was a risky strategy. The winters of 2009/10 and 2010/11, with their abnormally low temperatures (-16 °C and -17 °C were recorded in January and December 2010, respectively, whereas the normal average temperatures for the same months are +4.5 °C and +5.1 °C), highlighted that, although *E. nitens* was a very productive species, it was sensitive to very cold winter temperatures. This led to a revised planting strategy in 2010 where *E. nitens* was established in low frost risk areas within 30 km of the coast (depending on the topography) and where a series of other, more cold hardy species (*E. gunnii, E. rodwayi* A.T. Baker and H.G. Sm., *E. subcrenulat*a Maid. and Blakeley and several others) were established on colder, more inland sites. In addition, the strategy was modified to plant (where possible) in sites clustered close to where the material would be processed.

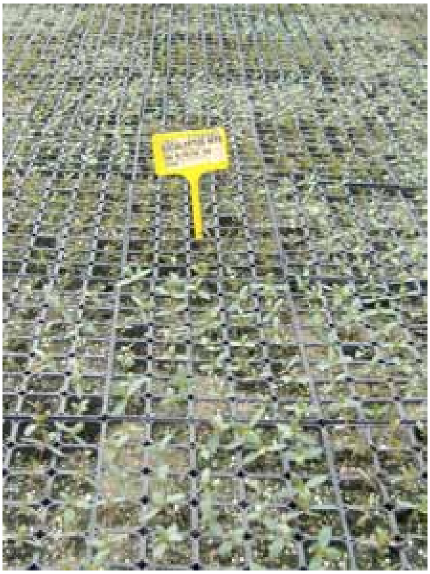

Figure 2: E. nitens *seed sown in containers and growing in a tunnel.*

Silviculture

Plant production

Because *Eucalyptus* seed is very small (about 250,000 seeds kg^{-1} of *E. nitens*) it is difficult to sow individual, or even a few seeds. Therefore, seed was either sown broadcast in seed trays and the young seedlings were transplanted into individual 100 cc cells and raised in tunnels, or it was sown directly into the cells using a precision vacuum seeder which sowed one to a few seeds per cell depending on the quality of the seed (Figure 2).

In the initial work of the Coillte 2008-2011 trials discussed above, seed was sown in containers in tunnels in early spring (February or March) with the objective to have 20 to 30 cm plants ready for field planting in May or June. The outcome of this produced soft, succulent, actively growing plants for planting, but which resulted in losses due to both mechanical damage from handling and from disease (*e.g. Botrytis*). Plants could not be held over on a site for any length of time because they were actively growing at the time of planting. This led to a change in production schedule.

In the trials established since 2009, seed was sown in containers in late spring (May to June) to produce a 25 to 30 cm plant by the end of the summer (Figure 3). Plants were grown initially in tunnels and moved out in early autumn (September) for hardening off. Plants were held in containers outdoors over winter until planting in the following spring (March to April). Dormant plants with a partly lignified stem were easier to handle than the softer actively growing plants. Timing of sowing has been shown to be critical to produce plants of the ideal size (25 to 30 cm). This size of plant is easy to handle and establishes well on reforestation sites. Larger plants are more difficult to plant and have a lower survival rate. Some species such as *E. nitens*

Figure 3: E. nitens *plants ready for field planting.*

will continue to grow in late autumn and early spring if conditions permit, so plants can be quite large (50 cm or more) at the time of planting.

Cold hardiness

The most limiting factor for *Eucalyptus* success in this country is probably low winter temperatures (Figure 4). Not only young crops, but also large trees, can be killed by low temperatures. Indeed, an 11-year-old stand of *E. nitens* near Tubbercurry in Co. Sligo in 2000 was seriously affected by a -14 °C temperature and a 16-year-old stand of E. nitens near Dundrum, Co. Tipperary in 2011 was severely damaged or killed by a temperature of ca. -15 °C. While material could be salvaged from these failures, the loss of a 3- to 4-year-old crop would be more serious because the trees would be too small to be worth harvesting.

However, cold hardiness is a complex and confusing problem to address. Published information on the cold hardiness of a species needs to be taken with some degree of caution. Often this information is not based on actual temperature measurements where the trees have been growing, but rather on meteorological station records

Figure 4: E. nitens *damaged by low temperatures in spring 2010 at Clogheen, Co. Tipperary.*

from a station some distance away. Extrapolating to field conditions based on such meteorological data is risky, perhaps providing at best some crude guidelines for where species might best be planted, but they do not provide any guarantee of success. In fact, they may provide unrealistic expectations.

Cold hardiness varies with the time of year and the temperatures the plants have previously experienced. Monthly computer controlled freezer tests were conducted between October and March on seedlings across a range of *Eucalyptus* species. In this process, 10 cm shoots were subjected to a series of target freezing temperatures (-5, -7, -9, -12, -15 and -18 ºC) for 3 hours in a programmable freezer. The series of freezing temperatures were selected to bracket the range causing a 50% damage as subsequently assessed by chlorophyll fluorescence (Perks et al. 2004). Seedlings grown in tunnels, which were moved outside in September, began to increase in cold hardiness in November, became most hardy during January and February, after which they began to lose cold hardiness. Plants assessed for their cold hardiness in the winter of 2010/2011, when temperatures at the nursery reached -10 ºC, became hardy to a lower temperature than the same species during the winter of 2011/2012, when the lowest temperatures at the nursery only reached -2 ºC. This showed that plants varied in their hardiness from year to year depending on the date and severity of the low temperatures experienced. Indeed, in some years with mild early autumn temperatures, plants might not reach their maximum hardiness until later in the winter. This could result in early autumn frost damage. Therefore, computer controlled freezing tests provide the most accurate estimates of cold hardiness of different species at the time of outplanting.

In addition to the levels of low temperatures experienced, the duration of the period of exposure to the low temperatures, the rapidity of the temperature change and how long this low temperature persists are important in the survival of the species. The rapidity of thawing in the morning, especially under sunny conditions, may also affect the level of damage. Many publications report only the "minimum low temperature a species can survive" (usually based only on "unofficial" local measurements), which is typically the temperature a species can survive for only a short period of time. However, exposure to a warmer low temperature for a longer time can be just as damaging. For example, Evans (1983b) suggested that while some species of *Eucalyptus* he considered to be "moderately hardy" were likely to survive short periods down to -14 ºC, but they could only survive long cold spells of -6 to -9 ºC.

Small variations in site conditions can result in differences in survival across a site. Low lying areas tend to collect cold air (e.g. frost pockets) and may experience much lower temperatures than slightly higher positions.

In addition to differences in cold hardiness among species, there are undoubtedly differences among the various seed sources or provenances within a species. For *E. gunnii*, different provenances are commercially available including Mienna, a very cold hardy but slow growing source, and Snug, a fast growing but less cold hardy source (Graham Milligan, personal communication 2010). Unfortunately there is very little of this type of provenance information available for the species of interest for use in Irish conditions. In addition, seed of different provenances of the main species of interest are generally not available, either for testing or commercial planting.

Minimum air temperatures may also not provide enough information on their own because in their native habitat, where temperatures of -15 °C are common, the presence of snow cover often prevents the ground from freezing. Some recovery from the base of *E. nitens* plants (whose aboveground sections had been killed) in December 2010 has been observed in Ireland, possibly because snow cover protected the roots from freezing.

Regarding cold hardiness, the main objective is to correctly assess the likely low temperatures on a given site and cautiously select species that should be able to easily tolerate the expected low temperatures. Not all sites are suitable for *Eucalyptus* and there will be some years, such as 2010, when even on good sites, extreme low-temperature events will occur and crops, both young and old, will be damaged or killed. The objective is to lengthen the odds of establishing a successful crop, by selecting the most suitable species and provenance.

Site selection

The importance of correct site selection for successful Eucalyptus establishment cannot be over emphasised. Fertile, sheltered, free draining lowland sites are best. On wet and exposed sites the potential for wind-throw needs to be considered. However, frost, freezing temperatures and perhaps soil type are the most limiting factors for *Eucalyptus* success in this country.

Soil requirements

Eucalyptus will do well on most soils with a few major exceptions. Deep peats are to be avoided. Most species prefer free draining soils and do not do well on waterlogged soils. In addition most species will not tolerate alkaline soils, although there are some species that can tolerate some soil alkalinity including *E. dalrympleana*, but most tolerant species do not grow well under our conditions.

Nutrition

Most *Eucalyptus* species originate from areas where soil nutrients are limited, particularly phosphorus and nitrogen. As a result, these species will respond to application of these nutrients, however, nutrients, especially nitrogen, may result in excessive shoot growth without complementary root growth. In the absence of any definitive studies at present, it is perhaps prudent to avoid applying any supplemental nutrition to *Eucalyptus* crops, especially nitrogen. Prudent application of low levels of phosphorus should not cause any problems and may prove to be beneficial, but further work in this area is needed.

Planting

Eucalyptus plants seem to benefit from any type of soil disturbance. Ripping if possible, is beneficial. Mounding can be also beneficial, but it increases the establishment costs which can adversely affect the economics of the crop (see section on Economic Analysis).

Figure 5: E. nitens *plantation after 2 growing seasons at Macroney, near Kilworth Co. Cork.*

Containerised plants can be planted with a dibble or spade, but it is important not to plant too deep or too shallow. If the peat plug is higher than the surrounding soil, it will lose moisture which will affect plant growth. Proper plant handling and minimum storage of plants on site before planting is necessary. Plants should not be allowed to dry out prior to planting.

Spacing

While conventional conifer silviculture in this country is based on 2,500 plants per hectare, this may be slightly higher than necessary for *Eucalyptus*. Estimates based on Irish trial results suggest that somewhere between 1,800 and 2,000 plants per hectare may be optimal for volume production, but this has not been systematically tested. Planting 2,500 plants per hectare without filling-in (unless there is exceptionally poor survival) should provide an adequately stocked stand for harvesting in 12 to 15 years. Filling in after the second full growing season will probably not be effective because of competition with the original plants, particularly if these have established well (Figure 5).

Vegetation control

Control of competing vegetation is essential for optimum *Eucalyptus* establishment and growth. *Eucalyptus* species are very sensitive to water stress and any shortage of water will inhibit growth. Failure to control vegetation will reduce growth. Competing vegetation may overtop the *Eucalyptus* and result in a delay in the establishment of the crop. Spraying a site with herbicides before planting is preferred because young *Eucalyptus* plants are susceptible to herbicide drift.

Growth and yield

Plots of *E. nitens* and *E. gunnii* around the country have provided data for the development of Irish production estimates (Figure 6). For *E. nitens* data from several of the 1992/93 plots show that an average maximum mean annual increment (MMAI) of 28 m^3 ha^{-1} yr^{-1} on a rotation length of 12 to 15 years is achievable (Table 1). This

Table 1: *Growth and yield data from three* Eucalyptus nitens *trials planted in 1993 and 1994, as well as one plot at JFK Arboretum planted in 1982*.

Trial	Age (years)	Stems (ha^{-1})	Mean BA (m^2ha^{-1})	Mean DBH cm	Stand BA m^2ha^{-1}	Mean vol. (m^3)	Stand vol. (m^3ha^{-1})	Top Ht. (m)	MAI ($m^3ha^{-1}yr^{-1}$)
CQN3	17	1770	0.0308	19.9	54.85	0.303	543.9	22.75	32.0
CQN7	17	1206	0.0377	21.8	43.69	0.388	444.6	25.06	26.2
DDM	17	1412	0.0340	20.6	47.98	0.340	482.9	23.79	28.4
GRY	16	740	0.0460	24.2	34.04	0.560	418.0	n.a.	26.1
JFK	28	950	0.0636	28.5	60.40	0.690	656.1	31.75	23.4

CQN3- Cappoquinn stand 3
CQN7- Cappoquinn stand 7
DDM- Dundrum
JFK- John F. Kennedy Arboretum
GRY- Gorey (Red Bog)

Figure 6: E. nitens *stand at Cappoquin, Co. Waterford at 18 years-of-age*.

compares favourably with data from Australian yield tables for *Eucalyptus*. Results for *E. gunnii* suggest a MMAI of 26 m^3 ha^{-1} yr^{-1}, but these were based on a limited number of trials.

Insects, diseases and animal damage

As an introduced species in Ireland, most *Eucalyptus* species do not suffer from the insects and disease that affect their productivity in their natural habitat. However, in 2007 the larval stage of a beetle, *Paropsisterna selmani,* from Australia was found on *Eucalyptus* being grown for foliage production is south-western Ireland. The insect caused defoliation of the crop, thus reducing productivity. The insect appears to have survived recent cold winters and also appears to be spreading. Because this leaf beetle has no natural predators here it may be able to spread unimpeded. Chemical control may be practical in foliage plantations but will not be practical in forest plantations. Probably the best solution might to develop a biological control agent, such as a naturally occurring insect that is a parasite of the beetle. This method has been used successfully to control a number of introduced insects, including some that attack *Eucalyptus* (Tribe, 2003). However, it is essential that the biological control agent specifically attacks only the target insect. Work to control this pest in Ireland is urgently needed.

Different *Eucalyptus* species vary in their palatability to animals including rabbits, deer and even grey squirrels. Most are not palatable, however *E. gunnii* has proved susceptible to browsing in areas where deer or rabbit populations are high. There is no evidence to show that *Eucalyptus* species are attacked by pine weevil.

Table 2: *Comparison of height growth rates, cold hardiness and coppicing ability of a range of* Eucalyptus *species planted in Ireland.*

Species	Growth Rates ($m yr^{-1}$)[a]		Cold Hardiness (°C)[b]		Coppicing Ability[c]
	JFK	UK	short periods	long periods	
E. nitens	1.5	-	-9 to -12	-6	poor
E. gunnii	1.2	1.4 to 1.8	-18	-10 to -14	good
E. glaucescens		1.4	-16	-10 to -12	good
E. rodwayii	1.3	-	-16	-10 to -12	good
E. subcrenulata		1.2	-14	-6 to -9	good
E. coccifera	1.0	0.9 to 1.5	-16	-10 to -12	poor
E. delagatensis	1.2	-	-14	-6 to -9	
E. dalrympleana	1.3	-	-12 to -14	-6 to -9	Good to medium

[a] Based on assessments in the UK by Benson (1994) and supplemented with measurements taken at the John F. Kennedy Arboretum, New Ross, Co. Wexford.
[b] Conservative estimates of cold hardiness (where death occurs in a majority of individuals) based on recommendations from Evans (1983a and b) and personal experience of the authors.
[c] From Nichols (2008).

Figure 7: *Coppicing from a harvested* E. nitens *stump.*

Coppicing

Different species vary in their ability to produce stump sprouts and coppice (Figure 7). Table 2 provides a summary of experience in New Zealand regarding the ability of several species to coppice. Coppice offers the ability to harvest several crops without replanting, but the ability to coppice should not be the main factor in species selection. However, the ability to coppice would be valuable for the recovery of young plantations that have suffered damage due to non-lethal low temperatures, browsing and even mechanical damage.

Species

Neilan and Thompson (2008) suggested six potential species for use in Ireland, recommendations that can now be further refined. Some details on the estimated growth rate, cold hardiness and coppicing ability of several species are presented in Table 2.

E. nitens (shining gum) is probably the fastest growing species than can be grown here, but it has limited frost hardiness which resulted in large losses during the winters of 2009/10 and again in 2010/11. It is best planted in low frost-risk sites within 30 km of the coast.

E. gunnii (cider gum) provides good growth (not as fast as *E. nitens*) with good frost hardiness, but it is subject to animal browsing.

E. subcrenulata (alpine yellow gum) is closely related to *E. johnstonii* (Maid.) which has shown promise in older Irish trials (Neilan and Thompson, 2008), but it grows at higher elevations in Tasmania and thus can better tolerate low temperatures. As a result, *E. subcrenulata* has replaced *E. johnstonii* as a suggested crop species.

E. rodwayi is largely an untested species in Ireland, although a line plot of this species in the Kennedy Arboretum has performed well.

E. glaucescens (Maid. and Blakeley) (Tingiringi gum) is another species which has not been widely tested but exists in a small plot at the Kennedy Arboretum; however, it has shown potential. The main problem with establishment using this species is the limited availability of seed.

Several of the other species discussed in Neilan and Thompson (2008) are no longer considered to have any compelling reason for their use.

The *E. johnstonii* has been replaced by the more cold tolerant *E. subcrenulata*, as discussed above.

E. globulus is really only a species for sites along the coast. All plants planted in trials away from the coast in 2010 have been killed by the low winter temperatures.

E. delagatensis although having performed well in one plot planted in 1993, a seedling crop developed a fungal leaf spot disease in the autumn of 2011 which caused plant production problems.

E. urnigera and *E. viminalis* although they have grown well in the past in Ireland, have only limited frost hardiness and are not as productive as some other species.

Economic analysis

The economic returns for *E. nitens* planted on reforestation sites were calculated for a range of options. The analyses included the expected yields, over various rotation lengths and haulage distances for a range of products including pulp, pallet and saw log. The results of the analysis for pulpwood products only showed that for crops with a mean annual increment (MAI) of 28 m^3 ha^{-1} yr^{-1} or more, it was economically viable for haulage up to 70 miles and for 15-year rotations because they exceeded the 5% Return on Investment criterion. Crops with a MAI of 26 were viable for haulage distances up to 50 miles. The returns increased significantly with increasing yield and the inclusion of saw log and/or energy products, which attracted a premium price.

A rotation length of 15 years was optimum for lower yielding sites and for longer haulage distances, while 12 years was optimum for MAI's above 36 and for shorter haulage distances.

Returns for planting *E. nitens* on afforestation sites were greater than for all other species. However, they were still insufficient to justify the purchase of land at current market prices. Some form of state financial support, similar to that available for other species, would be necessary to permit the purchase of land necessary for this afforestation option.

Utilisation

Sawn timber

E. nitens logs from a 16-year-old stand in Wexford were sent to Coillte's Dundrum sawmill to test its ability to produce sawn timber (Figure 8). As expected, problems were encountered during the drying process, including splitting, cracking and distortion. Nevertheless, samples of flooring, decking and cabinetry were produced. Methods were developed in Australia that showed that these problems with *E. nitens*

Figure 8: E. nitens *rough-sawn planks at Dundrum sawmill.*

timber can be overcome and that a successful business can be developed with this product (Cannon and Innes, 2008).

Samples of Irish grown *E. nitens* timber were sent to the Centre for Timber Engineering Department at Napier University in Edinburgh for testing. The results showed that, based on the stiffness and density, this material would have difficulty meeting the D30 strength class (the lowest strength grade for hardwood timber), as defined by EN 338. In comparison with similar published measurements of Australian grown *E. nitens*, the physical and mechanical properties of the Irish grown material were inferior. As a result, a significant effort would be needed to develop a market for Irish grown *Eucalyptus* as sawn timber.

Medium Density Fibreboard (MDF)

Logs harvested from a stand of *E. nitens* in Co. Wexford were transported to the Coillte MDF mill in Clonmel, Co. Tipperary. Significant difficulties were encountered during the debarking of the logs, mainly because the equipment at the mill was designed for conifer species. The *Eucalyptus* bark, unlike conifer bark which comes off in flakes, tended to come off in long strands, which wrapped around rollers and jammed the equipment. This was a technical problem which could be solved by altering or changing the debarking equipment or procedures. For testing purposes, logs were debarked manually and used to successfully produce MDF consisting of 75% conifer and 25% *Eucalyptus*. The board produced was broadly similar to that produced from 100% conifer chips and was sold through the normal distribution chain.

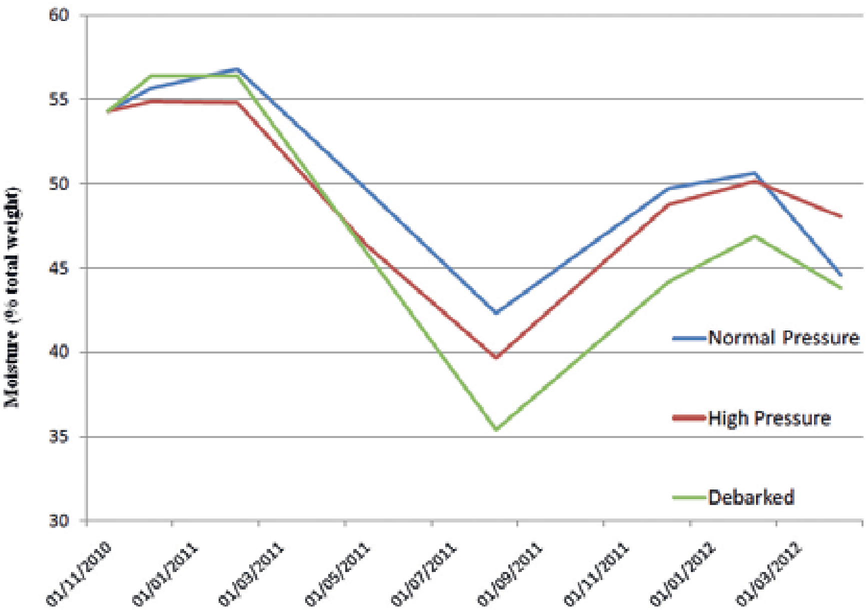

Figure 9: *Changes in moisture content of* E. nitens *logs over a 14-month period following three roller pressure treatments (Kent 2010).*

Orientated Strand Board (OSB)
Similar debarking problems were encountered at the Coillte OSB mill in Waterford. Manually debarked logs were flaked and sent to the University of North Wales where they were used to produce boards from 100% *Eucalyptus* material. This OSB board equalled or surpassed conifer boards over a range of test criteria.

Biomass for energy generation
Samples of *E. nitens* logs and lop and top were sent to the Wood Energy Research Group at the Waterford Institute of Technology for analysis. The wood density of Irish grown *E. nitens* was 435 kg m^{-3} and the bark accounted for 13% of the log weight. The gross calorific value of the round wood was 19 MJ kg^{-1} (dry weight) whereas the lop and top (leaves are known to have a high oil content) had a gross calorific value of 22.5 MJ kg^{-1}. Due mainly to the relatively higher density of its wood, the species produced 17% more energy per cubic metre than Sitka spruce.

Moisture content of wood is an important factor for both energy generation as well as fibre processing. A stand of *E. nitens* near the Coillte saw mill in Dundrum, Co. Tipperary was harvested in November 2010. Three different treatments were applied to the logs (Figure 9). The first was normal roller pressure of the harvesting head, the second was with an increased pressure of the harvesting head (to penetrate and perforate the bark to increase drying) and the third one involved manual removal of the bark. A stack of logs from each treatment was weighed periodically between

December 2010 and August 2011. Initial moisture content was 54%, which did not change between December 2010 and February 2011. By May 2011, the weight had reduced and further reductions were recorded between May 2011 and August 2011 in all treatments. In August 2011, the initial moisture content of 54% had fallen to 40% in the normal roller pressure treatment, 39% for the higher roller pressure and 35% in the debarked logs. The benefit of debarking *Eucalyptus* logs prior to processing is evident from these data.

Discussion

The results of trials of various *Eucalyptus* species over the last 100 years in Ireland have demonstrated that several species can be very productive. The main question, until very recently, was how can this material be used? Sawn timber continues to present problems, which could with time be resolved, but growing *Eucalyptus* for fibre or fuel offers the best potential end-uses at present.

There is much that is not known regarding the silvicultural management of *Eucalyptus* species in Irish conditions. Indeed some of the species and silvicultural practices discussed by Neilan and Thompson (2008) have now been revised (see above). Further information on species performance, site selection, soil and nutrient requirements, site preparation, planting stock production, vegetation control methods, spacing, rotation lengths, animal and insect damage and the ability to coppice need to be addressed.

It was, in hindsight, unwise early in the trials to concentrate entirely on one species (*E. nitens*), despite the attractiveness of the high productivity rates. The fact that *E. nitens* did not attain the level of frost hardiness necessary to survive the winters of 2009/10 and 2010/11 should not have been surprising given the failure of one of the 1994 trials of *E. nitens* in Sligo, also due to an abnormally cold period. Nevertheless, it is perhaps fortunate that this happened early on in the project, otherwise some of the more frost hardy species might not have been included in the trials.

As a result, it is prudent to have a selection of species that can cope with a range of site conditions. Certainly *E. nitens* has a place on sites with a low likelihood of frost, e.g. within 30 km of the sea. Other, more cold hardy species such as *E. gunnii* and *E. subcrenulata* can be planted on colder, more inland sites, while *E. rodwayi* and *E. glaucescens* also show potential for these sites but require further testing. Additional work is required to determine the best combination of species and location. Until this has been done, the planting of *Eucalyptus* should still be treated as experimental. Low winter temperatures, similar to the frosty and freezing conditions experienced in 2009/10 and 2010/11, can be expected to occur in the future, so caution is advised in species selection.

In addition to climatic challenges, the fact that a species of Eucalyptus leaf beetle has been found in the country could present a serious threat to these species. Because the insect has no natural pests, it could spread unhindered across the country affecting the productivity of all *Eucalyptus* species. The introduction of a natural parasite that affects only the target leaf beetle and no other organism, i.e. biological control, may be practical. This has been shown to be effective in other parts of the world, and, in fact it has already been used in Ireland to control another pest of a glaucous species of *Eucalyptus*, namely the blue gum psyllid (*Ctenarytaina eucalypti*: see Chauzat et al. 2002).

Conclusions

In spite of all these uncertainties, it appears that *Eucalyptus* can play a role in providing a source of fibre or fuel to help meet the current demands for this material in Ireland. With increased experience of *Eucalyptus* over time many of the current unknowns will be common knowledge in the future.

Practical implications

- A small number of fast growing, cold hardy *Eucalyptus* species have the potential to help bridge the gap between the forecasted supply and demand for woody biomass for energy on the island of Ireland.
- They can also be used in the production of fibre for panel board production.
- Care must be taken to match the species with the site, having regard to volume production and cold hardiness.
- More work is needed before definitive prescriptions can be given.

Acknowledgements

We wish to acknowledge the previous work of A.C. Forbes, O.V. Mooney and Michael Carey in providing the basis for this work. Assistance with some of the more recent results presented in this paper have been provided by Con Little and Pat Long. We also acknowledge the assistance of Henry Phillips and Dermot O'Brien for work on the economic analysis and growth models, Tom Kent for work on the energy and moisture content of *Eucalyptus* wood, Eamonn Kenny and T.J. O'Sullivan for the sawmilling trials, John Hannon and the staff at Medite for the MDF trials, Neil Foot and Michael Nichol of SmartPly for help with the OSB trials, Denis Buckley for developing growing regimes and producing plants for the field trials, and Kevin Black for the cold hardiness tests. The continued interest in *Eucalyptus* from 1993 to the present by Jim Neilan also needs to be recognised as providing the background to the work reported here.

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