

Five-year survival and growth of farm forestry plantings of native trees and radiata pine in pasture affected by position in the landscape

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Abstract. Woodlots ranging in area from 0.18 to 0.5 ha were established within the Cicerone Project farmlet trial on the Northern Tablelands of New South Wales, Australia, due to a lack of physical protection in most paddocks across the farmlets. Two percent of each farmlet was planted to trees to examine the commercial and environmental potential of seven species to provide shade and shelter for livestock, increase biodiversity or contribute to cash flow through farm forestry diversification. *Eucalyptus caliginosa* (timber), *E. nitens* (timber, pulp wood), *E. radiata* (essential oil) and *Pinus radiata* (timber) were planted in four upslope plots (1059–1062 m a.s.l.) in different paddocks. *Casuarina cunninghamiana* (timber, shelter), *E. acaciiformis* (shade, shelter and biodiversity), *E. dalrympleana* (timber, biodiversity), *E. nitens* (timber, pulp wood), *E. radiata* (essential oil) and *P. radiata* (timber) were planted in four low-lying plots (1046–1050 m a.s.l.) in separate paddocks, 400–1200 m distant. The pines and natives were planted in August and October 2003, respectively, into a well prepared, weed-free, mounded, planting bed. After 5 years, *P. radiata* (98% survival) and *E. nitens* (83%) survived best in upslope plots, reaching maximum heights of 7.8 and 8.8 m and exhibiting no or only modest insect damage, respectively. In low-lying plots, *E. acaciiformis* (75% survival) and *E. dalrympleana* (80%) survived best, reaching maximum heights of 5.5 and 4.5 m, and exhibiting little or only moderate insect damage, respectively. *P. radiata* exhibited 17–69% survival in the two lowest-lying plots but 100% survival in the other two lowland plots. On average, <50% of *C. cunninghamiana*, *E. nitens* and *E. radiata* survived in low-lying plots and survivors grew poorly. Early frosts in March 2004 were the primary cause of losses in low-lying plots, and frost, waterlogging, insect attack and some inadvertent livestock browsing explain the slower growth of species in low-lying plots compared with their performance upslope. *P. radiata* and perhaps *E. nitens* have commercial promise for timber production on Northern Tablelands farms, but only in higher (well drained, less frost-prone) parts of the landscape. *E. acaciiformis* can withstand the stressful growing conditions in open pasture in low-lying plots, and should be planted more widely for on-farm shade and shelter. *E. dalrympleana* can also be considered for amenity and biodiversity plantings in lower parts of the landscape.

Received 20 October 2011, accepted 2 March 2012, published online 10 July 2013

Introduction

Provision of shade, shelter and biodiversity is an important consideration for livestock grazing enterprises in landscapes with little tree cover (Reid and Wilson 1986; Bird *et al.* 1996; Abel *et al.* 1997; Cleugh 2003; Andrews *et al.* 2004). In the intensively developed parts of the Northern Tablelands of New South Wales (NSW), tree cover is often sparse or absent as a result of clearing for grazing, dieback (chronic defoliation of eucalypts, especially by pasture scarab beetles) and pasture improvement practices such as fertilisation and sown pasture establishment (Duggin 1981; Wylie *et al.* 1993; Taylor and Taylor 2004), as well as the inability of eucalypts to regenerate under high sheep grazing pressure or in competition with improved pastures (Reid *et al.* 1997; Reid and Landsberg 2000). In 2003, one-half of the region's woolgrowers thought that their farms had too little tree cover (Reeve 2006). These growers were planting, on average, 1200 trees per property annually to redress the issue.

Tree farming is also a potentially profitable enterprise on the Northern Tablelands (Harris 1998; Andrews *et al.* 2004). One local family has planted 15% of their property to trees over the past 25 years (Taylor and Taylor 2004), thereby diversifying their income base with several tree-based enterprises without reducing livestock carrying capacity. Farm families elsewhere in Australia have had similar experiences (e.g. Weatherstone 2003). While there is usually a trade-off between the timber and environmental or amenity benefits from farm tree planting (Stephen and Reid 1998), it is sensible to plant species that increase commercial options in the future while safeguarding livestock enterprises and enhancing biodiversity in the interim.

The Cicerone Project was a grazer-led research and adoption project which undertook a whole-farmlet study of different pasture and grazing management strategies on the Northern Tablelands of NSW, Australia (Sutherland *et al.* 2013). The three farmlets were set up to be matched in terms of total area,

biophysical similarity and prior management (Scott *et al.* 2013). In 2002, the Cicerone Board set a target of 8% of each farmlet to be planted to trees, with an initial establishment of 2% of the area. The decision arose from the widespread revegetation effort in the region (Curtis *et al.* 1995), the treeless exposed nature of the farmlets, and a wish to demonstrate profitable land-use alternatives to complement the livestock enterprises. The need for more shelter, especially for lambing, was underscored in spring 2003, when cold wet conditions resulted in significant losses of ewes and lambs at lambing (Hinch *et al.* 2013). Tree plots were positioned (R. Marchant, pers. comm.) such that each farmlet would benefit to the same extent from the shelter. Tree plot location at the edges of paddocks took into account the concepts of lambing paddock engineering developed by Holst and Marchant (2002), based on evidence of sheep camping behaviour (Taylor *et al.* 1984; Hatcher *et al.* 2010). As wind, with or without rain, is the main cause of mortality during lambing, the physical characteristics of a paddock's aspect, slope, sward height and topography can affect the chill index of a paddock at lamb height. The most important design factor was to provide shelter where the stock were likely to use it, especially considering the nocturnal camping behaviour of sheep as they prefer to camp in the highest, driest location in the paddock, generally facing north-east (Taylor *et al.* 1984). Thus, tree plots were located on the west side of flat paddocks or along the highest, south-westerly side of sloping paddocks. The location of tree plots in each farmlet is shown in fig. 2 of a companion paper in this Special Issue by Scott *et al.* (2013).

Following advice from several experts, seven species were chosen for planting: river oak (*Casuarina cunninghamiana*), wattle-leaved peppermint (*Eucalyptus acaciiformis*), New England stringybark (*E. caliginosa*), mountain white gum (*E. dalrympleana*), shining gum (*E. nitens*), narrow-leaved peppermint (*E. radiata*) and radiata pine (*Pinus radiata*). These were chosen for short-term (essential oil production: *E. radiata*) and medium to long-term commercial potential (timber: *E. nitens*, *P. radiata*, *C. cunninghamiana* and *E. caliginosa*), nitrogen fixation (*C. cunninghamiana*), environmental amenity (shade, shelter and windbreak effect: *E. acaciiformis*, *C. cunninghamiana*), and ability to withstand the difficult growing conditions of the Northern Tablelands (all species except perhaps *E. radiata*) (Bird *et al.* 1996; Jones 1997; Reid *et al.* 1997; Thompson 1997; Kar 2003; Andrews *et al.* 2004; Carr 2009). Species were partitioned among the low-lying (*C. cunninghamiana*, *E. acaciiformis*, *E. dalrympleana*, *E. nitens*, *E. radiata*) and higher elevation plots (*E. caliginosa*, *E. nitens*, *E. radiata*, *P. radiata*), depending on the species' known or suspected ability to grow in different parts of the landscape (Reid *et al.* 1997). Several commercial and semi-commercial plantations of *E. radiata* in the region produce cineole (Kar 2003; Doran *et al.* 2005). Given the differences in foliar cineole content among *E. radiata* provenances in south-eastern Australia, seven different seed lots were compared in upslope and low-lying plots. The native or exotic status of species was not the primary consideration in tree species selection because of the overriding objectives to establish species that would withstand the difficult tree-growing conditions and provide the specific ecosystem services identified above. Only *C. cunninghamiana*, *E. caliginosa* and *E. dalrympleana* had

natural populations locally (within a 10-km radius), although *E. acaciiformis*, *E. nitens* and *E. radiata* were native to the region (occurring naturally within a 100-km radius). In an initial report of the trial, Reid *et al.* (2005) summarised the costs of establishment and initial tree species survival after 14 months. In this paper, we compare the survival and growth of all seven species and the individual *E. radiata* seed lots after 5 years, in relation to landscape position (upslope vs low-lying plots) and canopy damage due to defoliating insects.

Methods

The Cicerone Project farmlets were located at the CSIRO McMaster research laboratory, 18 km south of Armidale, NSW (lat: S 30.52, long: E 151.67). The area was divided into three farmlets (A, B and C) of 53 ha each (Scott *et al.* 2013) and stocked with self-replacing flocks of superfine Merino ewes and some cattle during feed surplus periods between July 2000 and December 2006. Eight plots (0.18–0.50 ha each) totalling 3 ha were fenced from grazing for tree establishment over the 2002–03 summer, four plots (A8, B8, B7 and C9) in low-lying paddocks (1046–1050 m a.s.l.) and four (B3, C5, A4 and C6) in upslope paddocks (1059–1062 m). The plots were deep-ripped to a depth of 70 cm (four parallel rip-lines per planting line) in October 2002 and fenced. Tree lines were mounded in March 2003 and re-mounded in May 2003 to a height of 20 cm after the original mounds slumped (Reid *et al.* 2005). The planting lines were sprayed with glyphosate in May 2003 and again in August 2003 after rotary hoeing of mounds.

Trees were planted in August (pines) and October 2003 (other species) into weed-free, mounded, planting beds and watered in. Trees were planted at a spacing of 3 m in the row and 4 m between rows. The trees were sourced from Forests NSW (*P. radiata* GF 19 bare-rooted seedlings) and Kentucky Tree Nursery (Hiko seedlings of *Casuarina cunninghamiana* provenance Booroolong Creek, NSW; *E. acaciiformis* provenance Mt Agnes, Walcha; *E. caliginosa* provenance New England Highway, Kentucky; *E. dalrympleana* provenance Uralla, NSW; *E. nitens* provenance Major's Point, NSW, and *E. radiata*). Seven seed lots of *E. radiata* were included in the trial, five seed lots (Lot5, HHAP731, HHAP830, HHAP832 and HHAP1089) of southern Australian, high-cineole-yielding trees from the CSIRO Australian Tree Seed Centre and two seed lots from a plantation at Mount Yarrowyck, 31 km west of Armidale, NSW. The mother trees of the latter originated from the Oberon region (H. Harris, pers. comm.). Follow-up weed control (brush-cutting and over-spraying with a grass-specific herbicide, Fusilade) was undertaken in January and November 2004, and rabbit control was undertaken in October 2004.

In November 2008, 5 years after planting, the following details were recorded for each tree in all eight plots: species, survival, height (of the highest leaf), diameter at breast height (DBH) over bark of each stem at 1.3 m above the ground, foliage density, and insect, browse and frost damage. Foliage density was an estimate of the amount of living foliage expressed as a percentage of the potential quantity of foliage on the tree in full leaf (i.e. with a dense entire crown without dead or leafless branches; Reid *et al.* 1994). Leafless living trees scored 0% and trees with a perfect dense canopy scored 100%. Insect, browse

and frost damage were scored as the quantity of missing or dead foliage attributable to insect attack, sporadic mammalian browsing and frost, respectively, expressed as percentages of the actual quantity of foliage present. Average DBH per tree was calculated as the square root of the sum of the squares of the diameters of individual stems.

Response variables for each tree species per plot were percent survival, average tree height, maximum tree height, average DBH per tree, average number of stems per tree, basal area, average percent foliage density per tree, and average percent insect and browse damage per tree. Basal area of each species per plot was calculated as the sum of the basal area of each tree (calculated from the average DBH) divided by the area planted to that species. General and generalised linear models in R (R Development Core Team 2011) were used to analyse the effect of species (seven species, with *E. radiata* seed lots pooled) and position in the landscape (upslope vs downslope plots) on each response variable, with plot as the level of observation. Due to the unbalanced design (only three species were planted in both upslope and downslope plots), the interaction between species and landscape position had only two numerator degrees of freedom (d.f.). For the seven *E. radiata* seed lots, general or generalised linear models in R were used to test the effects of seed lot, landscape position and their interaction on each response variable. Model assumptions were checked by examining residual plots. Where parametric methods violated model assumptions, permutation tests were used. In two-factor analyses, the test of interaction was performed using a permutation *F*-test (Higgins 2004). The reported *F*-statistics were compared with the distribution of the permuted test statistics and the proportion of permuted statistics more extreme than the observed statistic determined (corresponding to a *P*-value). In single-factor analyses, k-sample permutation tests calculated the observed value of the test statistic, maxT (Hothorn *et al.* 2008), and *P*-values were determined as before. Significant differences in response variables among species for each landscape position were determined using *post hoc* Bonferroni tests. For all trees with a measurable DBH, pairwise correlations were calculated among three tree response variables (individual tree height, DBH and foliage density) and two explanatory variables, elevation and soil 'type', which were recorded in each plot. Soil 'type' was a numeric score measured with an EM31, reflecting the quantity of clay, soil moisture and electrical conductivity in the top 5 m of soil (Scott *et al.* 2013).

Results

All species

Some 2157 trees were planted in the eight woodlot plots. Survival after 5 years was greater in upslope plots (85.4%, $n = 1101$) than in low-lying plots (37.5%, $n = 1056$). Survival percentage of the three species planted in all plots (*E. nitens*, *E. radiata* and *P. radiata*) varied significantly with elevation and species (Table 1). The survival of all species in upslope plots (including *E. caliginosa*) was generally good (Table 1), average survival varying from 78.8 to 98.4%, but with *P. radiata* having significantly greater survival than the eucalypts. Survival of species in low-lying plots was more variable: three species,

E. acaciiformis, *E. dalrympleana* and *P. radiata*, had survival percentages (71.5–81.0%) similar to upslope eucalypts, but three species performed poorly (*Casuarina cunninghamiana*, *E. nitens* and *E. radiata*, 14.0–24.0%).

Some 1336 trees (62%) were alive after 5 years. Average tree height of the three species in all plots (*P. radiata*, *E. nitens* and *E. radiata*) was greater upslope (3.2–6.2 m) than down (1.5–3.2 m) and varied with species. In upslope plantings, average tree height of *E. nitens* and *P. radiata* (5.8–6.2 m) was significantly greater than *E. caliginosa* and *E. radiata* (3.2–3.4 m), but mean height did not vary among species in downslope plantings (1.5–3.5 m). Mean maximum tree height of species in upper and lower plots followed a similar trend as average tree height, except that the tallest *E. caliginosa* individuals in upslope plots rivalled the tallest *P. radiata*.

The number of trees that were >1.3 m in height and had a measurable DBH, totalled 1195. Consistent with survival and height, average DBH of the three species planted in each plot was significantly greater in upslope (5.2–10.7 cm) than low-lying (3.5–5.3 cm) plots, and varied with species (Table 1). In upslope plots, the mean DBH (\pm s.e.m.) of *P. radiata* (10.7 ± 0.83 cm) was significantly greater than that of *E. caliginosa* (7.5 ± 0.87 cm) or *E. radiata* (5.2 ± 0.20 cm). Downslope, *E. acaciiformis* DBH (10.3 ± 1.16 cm) was significantly greater than *E. radiata* (3.5 ± 0.09 cm) and *C. cunninghamiana* DBH (1.4 ± 0.27 cm). Most species had an average of 1.0–1.1 stems per tree but some species averaged significantly more (Table 1). The three species common to all plots varied in mean number of stems, with *E. nitens* averaging 1.0 ± 0.02 stem per tree and *E. radiata* averaging 1.2–1.3 stems per tree. Species in low-elevation plots also varied significantly in number of stems, with *E. acaciiformis* averaging 2.3 ± 0.16 stems per tree compared with *C. cunninghamiana* (1.0 ± 0.00) and *E. nitens*.

Consistent with survival, height and DBH, basal area of the three species planted in all plots varied with landscape position and species (Table 1). The mean basal area in upslope plots (1.43 – 8.05 m²/ha) was significantly greater than downslope (0.03 – 1.62 m²/ha). Upslope, the mean basal area of *P. radiata* (8.05 m²/ha) and *E. nitens* (5.53 m²/ha) exceeded that of *E. radiata* (1.43 m²/ha), and mean basal area of *P. radiata* also exceeded that of *E. caliginosa* (3.12 m²/ha). At lower elevation, mean basal area of *E. acaciiformis* (5.87 m²/ha) eclipsed that of *C. cunninghamiana*, *E. nitens* and *E. radiata* (0.02 – 0.62 m²/ha), but was not significantly greater than *E. dalrympleana* (2.92 m²/ha) or *P. radiata* (1.62 m²/ha).

Calculated stem volume varied between 16.76 ± 2.52 m³/ha for *P. radiata* in upland plots and as little as 0.02 ± 0.02 m³/ha for *C. cunninghamiana* in low-elevation plots. The interaction between landscape position and species was significant for the volume of the three species planted in all plots (Table 1): *P. radiata* and *E. nitens* had substantial stem volumes in upslope plots (13.48 – 16.76 m³/ha) unlike downslope plots (1.09 – 2.24 m³/ha) or the volume of *E. radiata* in either landscape position (0.03 – 1.43 m³/ha). Considering all four species planted in upland plots, *E. nitens* and *P. radiata* had significantly greater volumes than *E. radiata* and *E. caliginosa* (2.04 – 5.16 m³/ha). Downslope, *E. dalrympleana* and *E. acaciiformis* (4.16 – 8.88 m³/ha) had greater volumes than

Table 1. Performance of seven tree species in plantings on upper slopes and flats in the Cicero experiment

Data in the upper panels are test statistics (d.f.) for model terms (landscape position, species and their interaction) based on general linear models of the untransformed data unless otherwise indicated, and considering only the three species planted in both landscape positions. Data in the lower panels are test statistics for the comparison of all species in the respective landscape position, and means \pm 1 s.e.m. (no. of plots) for each species attribute. Within columns, means followed by different letters are significantly different at $P = 0.05$ (Bonferroni contrasts). *, $P \leq 0.05$; **, $P \leq 0.01$; ***, $P \leq 0.001$

Model terms	Survival (%)	Height (m)	Max. height (m)	Diameter at breast height (cm)	No. of stems ^A
Landscape position \times species	$F = 2.51$ n.s. (2,18)	$F = 1.42$ n.s. (2,17)	$F = 0.37$ n.s. (2,17)	$F = 2.42$ n.s. (2,15)	$F = 1.00$ n.s.
Landscape position	$F = 39.8$ *** (1,20)	$F = 45.2$ *** (1,19)	$F = 33.3$ *** (1,19)	$F = 30.6$ *** (1,17)	$F = 4.82$ ^C
Species	$F = 8.86$ ** (2,20)	$F = 14.7$ ** (2,19)	$F = 4.91$ * (2,19)	$F = 11.4$ *** (2,17)	$F = 11.0$ **
Test statistic (d.f.)	Upper slopes	Upper slopes	Upper slopes	Upper slopes	Upper slopes
	$F = 8.46$ ** (3,12)	$F = 9.19$ *** (5,18)	$F = 22.9$ *** (3,12)	$F = 12.4$ ** (3,12)	maxT = 2.49 n.s.
<i>Casuarina cunninghamiana</i>	82.7 \pm 3.5 (4)a	16.3 \pm 9.5 (4)a	3.4 \pm 0.26 (4)a	1.4 \pm 0.27 (2)a	1.0 \pm 0.00 (2)a
<i>Eucalyptus acaciiformis</i>	—	74.6 \pm 7.0 (4)c	—	10.3 \pm 1.16 (4)b	2.3 \pm 0.16 (4)b
<i>Eucalyptus caliginosa</i>	—	—	—	—	—
<i>Eucalyptus dalrympleana</i>	80.1 \pm 6.7 (4)c	80.1 \pm 6.7 (4)c	3.4 \pm 0.29 (4)	6.6 \pm 1.23 (4)ab	1.5 \pm 0.19 (4)ab
<i>Eucalyptus nitens</i>	82.8 \pm 4.3 (4)a	24.0 \pm 8.2 (4)ab	6.2 \pm 0.50 (4)b	5.2 \pm 1.66 (3)ab	1.0 \pm 0.02 (3)a
<i>Pinus radiata</i>	98.4 \pm 1.2 (4)b	71.5 \pm 19.5 (4)bc	5.8 \pm 0.33 (4)b	10.7 \pm 0.83 (4)b	1.1 \pm 0.06 (4)ab
<i>Eucalyptus radiata</i>	78.8 \pm 1.8 (4)a	14.0 \pm 4.8 (4)a	3.2 \pm 0.13 (4)a	5.3 \pm 0.60 (4)ab	1.3 \pm 0.04 (2)ab
				3.5 \pm 0.09 (2)a	
				7.5 \pm 0.87 (4)a	1.1 \pm 0.05 (4)
				4.6 \pm 0.53 (4)	—
				4.5 \pm 1.34 (4)	—
				4.9 \pm 0.66 (4)	1.0 \pm 0.01 (4)
				2.5 \pm 0.20 (4)a	1.0 \pm 0.01 (4)
				6.2 \pm 0.40 (4)a	1.2 \pm 0.06 (4)
				8.8 \pm 0.87 (4)b	—
				7.8 \pm 0.18 (4)ab	—
				6.2 \pm 0.28 (3)	—
				2.5 \pm 0.40 (4)a	—
				4.9 \pm 0.66 (4)	—
				10.7 \pm 0.83 (4)b	—
				5.3 \pm 0.60 (4)ab	—
				5.2 \pm 1.66 (3)ab	—
				9.5 \pm 0.63 (4)ab	—
				4.5 \pm 1.34 (4)	—
				4.6 \pm 0.53 (4)	—
				4.9 \pm 0.66 (4)	—
				6.2 \pm 0.40 (4)a	—
				7.5 \pm 0.87 (4)a	—
				8.8 \pm 0.87 (4)b	—
				10.7 \pm 0.83 (4)b	—
				5.3 \pm 0.60 (4)ab	—
				5.2 \pm 1.66 (3)ab	—
				9.5 \pm 0.63 (4)ab	—
				4.5 \pm 1.34 (4)	—
				4.6 \pm 0.53 (4)	—
				4.9 \pm 0.66 (4)	—
				6.2 \pm 0.40 (4)a	—
				7.5 \pm 0.87 (4)a	—
				8.8 \pm 0.87 (4)b	—
				10.7 \pm 0.83 (4)b	—
				5.3 \pm 0.60 (4)ab	—
				5.2 \pm 1.66 (3)ab	—
				9.5 \pm 0.63 (4)ab	—
				4.5 \pm 1.34 (4)	—
				4.6 \pm 0.53 (4)	—
				4.9 \pm 0.66 (4)	—
				6.2 \pm 0.40 (4)a	—
				7.5 \pm 0.87 (4)a	—
				8.8 \pm 0.87 (4)b	—
				10.7 \pm 0.83 (4)b	—
				5.3 \pm 0.60 (4)ab	—
				5.2 \pm 1.66 (3)ab	—
				9.5 \pm 0.63 (4)ab	—
				4.5 \pm 1.34 (4)	—
				4.6 \pm 0.53 (4)	—
				4.9 \pm 0.66 (4)	—
				6.2 \pm 0.40 (4)a	—
				7.5 \pm 0.87 (4)a	—
				8.8 \pm 0.87 (4)b	—
				10.7 \pm 0.83 (4)b	—
				5.3 \pm 0.60 (4)ab	—
				5.2 \pm 1.66 (3)ab	—
				9.5 \pm 0.63 (4)ab	—
				4.5 \pm 1.34 (4)	—
				4.6 \pm 0.53 (4)	—
				4.9 \pm 0.66 (4)	—
				6.2 \pm 0.40 (4)a	—
				7.5 \pm 0.87 (4)a	—
				8.8 \pm 0.87 (4)b	—
				10.7 \pm 0.83 (4)b	—
				5.3 \pm 0.60 (4)ab	—
				5.2 \pm 1.66 (3)ab	—
				9.5 \pm 0.63 (4)ab	—
				4.5 \pm 1.34 (4)	—
				4.6 \pm 0.53 (4)	—
				4.9 \pm 0.66 (4)	—
				6.2 \pm 0.40 (4)a	—
				7.5 \pm 0.87 (4)a	—
				8.8 \pm 0.87 (4)b	—
				10.7 \pm 0.83 (4)b	—
				5.3 \pm 0.60 (4)ab	—
				5.2 \pm 1.66 (3)ab	—
				9.5 \pm 0.63 (4)ab	—
				4.5 \pm 1.34 (4)	—
				4.6 \pm 0.53 (4)	—
				4.9 \pm 0.66 (4)	—
				6.2 \pm 0.40 (4)a	—
				7.5 \pm 0.87 (4)a	—
				8.8 \pm 0.87 (4)b	—
				10.7 \pm 0.83 (4)b	—
				5.3 \pm 0.60 (4)ab	—
				5.2 \pm 1.66 (3)ab	—
				9.5 \pm 0.63 (4)ab	—
				4.5 \pm 1.34 (4)	—
				4.6 \pm 0.53 (4)	—
				4.9 \pm 0.66 (4)	—
				6.2 \pm 0.40 (4)a	—
				7.5 \pm 0.87 (4)a	—
				8.8 \pm 0.87 (4)b	—
				10.7 \pm 0.83 (4)b	—
				5.3 \pm 0.60 (4)ab	—
				5.2 \pm 1.66 (3)ab	—
				9.5 \pm 0.63 (4)ab	—
				4.5 \pm 1.34 (4)	—
				4.6 \pm 0.53 (4)	—
				4.9 \pm 0.66 (4)	—
				6.2 \pm 0.40 (4)a	—
				7.5 \pm 0.87 (4)a	—
				8.8 \pm 0.87 (4)b	—
				10.7 \pm 0.83 (4)b	—
				5.3 \pm 0.60 (4)ab	—
				5.2 \pm 1.66 (3)ab	—
				9.5 \pm 0.63 (4)ab	—
				4.5 \pm 1.34 (4)	—
				4.6 \pm 0.53 (4)	—
				4.9 \pm 0.66 (4)	—
				6.2 \pm 0.40 (4)a	—
				7.5 \pm 0.87 (4)a	—
				8.8 \pm 0.87 (4)b	—
				10.7 \pm 0.83 (4)b	—
				5.3 \pm 0.60 (4)ab	—
				5.2 \pm 1.66 (3)ab	—
				9.5 \pm 0.63 (4)ab	—
				4.5 \pm 1.34 (4)	—
				4.6 \pm 0.53 (4)	—
				4.9 \pm 0.66 (4)	—
				6.2 \pm 0.40 (4)a	—
				7.5 \pm 0.87 (4)a	—
				8.8 \pm 0.87 (4)b	—
				10.7 \pm 0.83 (4)b	—
				5.3 \pm 0.60 (4)ab	—
				5.2 \pm 1.66 (3)ab	—
				9.5 \pm 0.63 (4)ab	—
				4.5 \pm 1.34 (4)	—
				4.6 \pm 0.53 (4)	—
				4.9 \pm 0.66 (4)	—
				6.2 \pm 0.40 (4)a	—
				7.5 \pm 0.87 (4)a	—
				8.8 \pm 0.87 (4)b	—
				10.7 \pm 0.83 (4)b	—
				5.3 \pm 0.60 (4)ab	—
				5.2 \pm 1.66 (3)ab	—
				9.5 \pm 0.63 (4)ab	—
				4.5 \pm 1.34 (4)	—
				4.6 \pm 0.53 (4)	—
				4.9 \pm 0.66 (4)	—
				6.2 \pm 0.40 (4)a	—
				7.5 \pm 0.87 (4)a	—
				8.8 \pm 0.87 (4)b	—
				10.7 \pm 0.83 (4)b	—
				5.3 \pm 0.60 (4)ab	—
				5.2 \pm 1.66 (3)ab	—
				9.5 \pm 0.63 (4)ab	—
				4.5 \pm 1.34 (4)	—
				4.6 \pm 0.53 (4)	—
				4.9 \pm 0.66 (4)	—
				6.2 \pm 0.40 (4)a	—
				7.5 \pm 0.87 (4)a	—
				8.8 \pm 0.87 (4)b	—
				10.7 \pm 0.83 (4)b	—
				5.3 \pm 0.60 (4)ab	—
				5.2 \pm 1.66 (3)ab	—
				9.5 \pm 0.63 (4)ab	—
				4.5 \pm 1.34 (4)	—
				4.6 \pm 0.53 (4)	—
				4.9 \pm 0.66 (4)	—
				6.2 \pm 0.40 (4)a	—
				7.5 \pm 0.87 (4)a	—
				8.8 \pm 0.87 (4)b	—
				10.7 \pm 0.83 (4)b	—
				5.3 \pm 0.60 (4)ab	—
				5.2 \pm 1.66 (3)ab	—
				9.5 \pm 0.63 (4)ab	—
				4.5 \pm 1.34 (4)	—
				4.6 \pm 0.53 (4)	—
				4.9 \pm 0.66 (4)	—
				6.2 \pm 0.40 (4)a	—
				7.5 \pm 0.87 (4)a	—
				8.8 \pm 0.87 (4)b	—
				10.7 \pm 0.83 (4)b	—
				5.3 \pm 0.60 (4)ab	—
				5.2 \pm 1.66 (3)ab	—
				9.5 \pm 0.63 (4)ab	—
				4.5 \pm 1.34 (4)	—
				4.6 \pm 0.53 (4)	—
				4.9 \pm 0.66 (4)	—

C. cunninghamiana and *E. radiata* ($0.02\text{--}0.03\text{ m}^3/\text{ha}$). *E. nitens* and *P. radiata* had intermediate volumes.

Mean foliage density varied from $88.2 \pm 5.71\%$ for *P. radiata* in upland plots to as little as $16.9 \pm 8.19\%$ for *C. cunninghamiana* in downslope plots. Foliage density of species planted in all plots varied with landscape position and species (Table 1), with all three species in upslope plots having mean foliage densities 15–34% greater than in lowland plots. In upslope plots, *E. caliginosa* (52.0%) had significantly less foliage density than *E. nitens* and *E. radiata* (64.9–68.7%), which in turn had less foliage density than *P. radiata*. Downslope, the foliage density of *C. cunninghamiana* and *E. radiata* (34.7%) was significantly less than *P. radiata* (72.9%) and *E. acaciiformis* (75.6%), with *E. nitens* and *E. dalrympleana* (42.2–51.3%) having intermediate foliage densities.

On average, between 0.0 and 27.2% of the canopy of the plantings of various species in upslope and downslope plots was affected by insect damage (Table 1). Both landscape position and species were significant for insect damage in the three species planted in all plots. *P. radiata* suffered no or negligible insect damage, while *E. nitens* and *E. radiata* suffered moderate foliage attack upslope (9.8–11.7%) and substantial damage downslope (25.2–27.2%). The percentage of the canopy damaged by insects proved difficult to model due to an absence of insect damage in most plantings of *P. radiata* and *C. cunninghamiana* (0.0–0.9% foliar damage per plot). *E. acaciiformis* (8.5%) and upland plantings of *E. radiata*, *E. nitens* and *E. caliginosa* (9.8–16.0%) suffered intermediate levels of insect attack whereas lowland plantings of *E. dalrympleana*, *E. nitens* and *E. radiata* suffered substantial foliage loss (22.4–27.2%). Sheep and cattle briefly gained access to plantings in two lowland paddocks (B7 and C9) twice. They browsed *Casuarina cunninghamiana* severely, resulting in a mean loss of 78.6% of canopy in that species, and inflicted modest damage on other species (7.3–13.9% canopy browse damage, averaged across all lowland paddocks).

Eucalyptus radiata seed lots

Survival of the various *E. radiata* seed lots was fair to good upslope (79.2% pooled over all seed lots), and significantly better than on the flat (14.0%, Table 2). Lot 5 survived best in both landscape positions and Oberon1 exhibited worst survival, but variation due to seed lot was not significant. Similar to survival, the average height, maximum height, DBH, basal area, volume, foliage density and amount of foliar insect damage of the seven *E. radiata* seed lots varied significantly with landscape position. However, the effects of seed lot and the interaction between position in the landscape and seed lot were not significant (Table 2). Upslope plantings were taller with a larger DBH, basal area and volume than the few surviving trees on the flat. Upslope *E. radiata* also had more foliage and suffered less foliar insect attack. The poor canopy condition of surviving *E. radiata* downslope was partly attributable to sporadic livestock browsing and the effect of a recent frost in one plot (data not shown). The average number of stems per *E. radiata* did not vary significantly with seed lot or landscape position (Table 2), averaging 1.2 ± 0.06 stems per tree per plot ($n = 38$).

Correlations among response and explanatory variables

Among the 1195 surviving trees with height >1.3 m, individual tree height and DBH were strongly correlated. Tree height was most strongly correlated with elevation (Pearson $r = 0.38$) followed by foliage density (0.36) and soil type (0.15) whereas DBH was most strongly correlated with foliage density (0.44) and elevation (0.31). Foliage density was only weakly correlated with elevation. Although soil type was strongly correlated with elevation, soil type was not correlated with either tree height, DBH or foliage density.

Discussion

Project resource constraints and its relatively short duration meant that the original goal of establishing trees plots on 8% of each farmlet area was not realised by the end of the Cicerone farmlet experiment (December 2006). Although farmlet areas with and without trees were not established to quantify effects of tree protection on lambing ewes, anecdotal evidence was that within the first 3 years, the tree plots had begun to provide useful shelter for livestock as lambing losses declined slightly over time (Hinch *et al.* 2013).

Species performance

After 5 years, *P. radiata* and *E. nitens* were the best performing species in upslope plots, with high average survival (83–98%), good average and maximum height (5.8–6.2 and 7.8–8.8 m, respectively), large average stem diameters (9.5–10.7 cm), single stems, modest basal area (5.5–8.0 m^2/ha) and volumes (13.5–16.8 m^3/ha), and moderate to good foliage density (65–88%) with little or no foliar insect damage (0–12%). Upslope plantings of these two species did not differ significantly in average height, maximum height, stem diameter, basal area or stem volume. However, *P. radiata* performed better than *E. nitens* in survival, foliage density and resistance to foliar insect attack, and marginally better in stem diameter, basal area and stem volume. *E. nitens*, on the other hand, was marginally taller than *P. radiata*. The average height and calculated stem volume of *P. radiata* and *E. nitens* were significantly greater than that of the other two species in upslope plots, *E. caliginosa* and *E. radiata* (3.2–3.4 and 2.04–5.16 m^3/ha , respectively). In other respects, the survival (78.8–82.7%), mean stem diameter (5.2–7.5 cm) and foliar insect damage (9.8–16.0%) of *E. caliginosa* and *E. radiata* were similar to the values recorded for upslope *E. nitens*. Average maximum height (6.8 m) and basal area (3.12 m^2/ha) of *E. caliginosa* approached that of *P. radiata* and *E. nitens*, respectively, and the foliage density of *E. radiata* (69%) did not vary significantly from that of *E. nitens*. The upslope plantings of all four species were more or less single-stemmed.

The performance of the six species in low-lying plots on the flat was variable and moderate at best. *E. acaciiformis* performed best, rivalling upslope *P. radiata* and *E. nitens* in mean stem diameter (10.3 cm) and the latter in basal area (5.87 m^2/ha), foliage density (75.6%) and the low amount of foliar insect damage (8.5%). *E. acaciiformis* plantings on the flat approached upslope *P. radiata* and *E. nitens* plantings in terms of survival percentage (74.6%), average (3.5 m) and maximum height (5.5 m), and calculated stem volume (8.88 m^3/ha).

Table 2. Performance of seven *Eucalyptus radiata* seed lots in plantings on upper slopes and flats in the Cicerone experiment

Data in the upper panels are test statistics (d.f.) for model terms (landscape position, seed lot and their interaction) based on general linear models of the untransformed data, unless otherwise indicated. Data in the lower panels are means \pm 1 s.e.m. (no. of plots) for each tree attribute. *, $P \leq 0.05$; **, $P \leq 0.01$; ***, $P \leq 0.001$

Model terms	Survival (%) ^A	Height (m)	Max. height (m)	Diameter at breast height (cm)	No. of stems ^B					
Landscape position \times seedlot	$F = 0.41$ n.s. (6,42)	$F = 1.23$ n.s. (6,28)	$F = 0.66$ n.s. (6,28)	$F = 1.95$ n.s. (4,18)	$F = 1.06$ n.s.					
Landscape position	$F = 150.0$ *** (1,48)	$F = 47.8$ *** (1,34)	$F = 73.6$ *** (1,34)	$F = 9.99$ ** (1,22)	$F = 0.18$ n.s.					
Seedlot	$F = 1.60$ n.s. (6,49)	$F = 0.55$ n.s. (6,34)	$F = 1.24$ n.s. (6,34)	$F = 0.38$ n.s. (4,22)	$F = 0.94$ n.s.					
	Upper slopes	Flats	Upper slopes	Flats	Upper slopes	Flats				
All seed lots	79.2 \pm 3.8 (28)	14.0 \pm 3.1 (28)	3.2 \pm 0.12 (28)	1.6 \pm 0.19 (14)	4.7 \pm 0.21 (28)	1.9 \pm 0.21 (14)	5.1 \pm 0.25 (28)	3.1 \pm 0.46 (8)	1.2 \pm 0.04 (28)	1.4 \pm 0.26 (8)
<i>E. radiata</i> Oberon2	86.4 \pm 7.2 (4)	12.0 \pm 7.0 (4)	3.2 \pm 0.15 (4)	2.3 \pm 0.48 (2)	5.3 \pm 0.83 (4)	2.7 \pm 0.30 (2)	5.2 \pm 0.44 (4)	3.0 \pm 1.00 (2)	1.2 \pm 0.09 (4)	1.0 \pm 0.00 (2)
<i>E. radiata</i> Oberon1	55.7 \pm 6.8 (4)	1.9 \pm 1.9 (4)	2.5 \pm 0.50 (4)	2.4 (1)	3.7 \pm 0.80 (4)	2.4 (1)	3.7 \pm 1.00 (4)	5.4 (1)	1.1 \pm 0.13 (4)	3.0 (1)
<i>E. radiata</i> Lot5	92.8 \pm 2.9 (4)	28.3 \pm 10.9 (4)	3.4 \pm 0.22 (4)	1.8 \pm 0.59 (3)	4.8 \pm 0.37 (4)	2.3 \pm 0.58 (3)	5.5 \pm 0.29 (4)	3.1 \pm 0.25 (2)	1.2 \pm 0.08 (4)	1.5 \pm 0.50 (2)
<i>E. radiata</i> HHAP1089	88.9 \pm 6.4 (4)	8.9 \pm 5.6 (4)	3.2 \pm 0.37 (4)	1.2 \pm 0.3 (2)	5.0 \pm 0.17 (4)	1.5 \pm 0.60 (2)	5.0 \pm 0.66 (4)	3.0 (1)	1.2 \pm 0.07 (4)	1.0 (1)
<i>E. radiata</i> HHAP832	72.2 \pm 12.1 (4)	12.0 \pm 7.0 (4)	3.1 \pm 0.17 (4)	1.2 \pm 0.07 (2)	4.1 \pm 0.16 (4)	1.5 \pm 0.20 (2)	4.9 \pm 0.38 (4)	–	1.3 \pm 0.11 (4)	–
<i>E. radiata</i> HHAP731	76.7 \pm 16.3 (4)	25.1 \pm 9.2 (4)	3.4 \pm 0.47 (4)	1.5 \pm 0.43 (3)	4.8 \pm 0.47 (4)	1.8 \pm 0.46 (3)	6.0 \pm 0.93 (4)	2.2 \pm 1.25 (2)	1.2 \pm 0.12 (4)	1.0 \pm 0.00 (2)
<i>E. radiata</i> HHAP830	82.6 \pm 4.6 (4)	10.0 \pm 10.0 (4)	3.3 \pm 0.27 (4)	0.9 (1)	5.0 \pm 0.59 (4)	0.9 (1)	5.3 \pm 0.52 (4)	–	1.2 \pm 0.11 (4)	–
Model terms	Basal area (m ² /ha) ^C	Volume (m ³ /ha) ^D	Foliage density (%)	Insect damage (%) ^E						
Landscape position \times seedlot	$F = 1.21$ n.s. (6,42)	$F = 1.26$ n.s. (6,42)	$F = 0.91$ n.s. (6,28)	$F = 1.14$ n.s. (6,28)						
Landscape position	$F = 264.4$ ** (1,48)	$F = 264.8$ * (1,48)	$F = 20.2$ *** (1,34)	$F = 6.89$ * (1,34)						
Seedlot	$F = 1.67$ n.s. (6,48)	$F = 1.84$ n.s. (6,48)	$F = 0.57$ n.s. (2,34)	$F = 0.49$ n.s. (6,34)						
	Upper slopes	Flats	Upper slopes	Flats	Upper slopes	Flats				
All seed lots	1.4 \pm 0.13 (28)	0.0 \pm 0.01 (28)	2.0 \pm 0.22 (28)	0.0 \pm 0.01 (28)	68.1 \pm 2.5 (28)	38.4 \pm 7.4 (14)	9.8 \pm 1.9 (28)	29.1 \pm 5.5 (14)		
<i>E. radiata</i> Oberon2	1.5 \pm 0.17 (4)	0.07 \pm 0.06 (4)	2.3 \pm 0.47 (4)	0.7 \pm 0.06 (4)	75.6 \pm 6.3 (4)	57.5 \pm 17.5 (2)	7.5 \pm 3.9 (4)	10.0 \pm 0.0 (2)		
<i>E. radiata</i> Oberon1	0.6 \pm 0.27 (4)	0.04 \pm 0.04 (4)	0.8 \pm 0.41 (4)	0.0 \pm 0.03 (4)	61.2 \pm 12.0 (4)	70.0 (1)	10.8 \pm 5.7 (4)	0.0 (1)		
<i>E. radiata</i> Lot5	2.0 \pm 0.30 (4)	0.6 \pm 0.05 (4)	2.7 \pm 0.55 (4)	0.1 \pm 0.05 (4)	71.5 \pm 3.2 (4)	43.2 \pm 16.1 (3)	6.5 \pm 2.9 (4)	26.9 \pm 14.2 (3)		
<i>E. radiata</i> HHAP1089	1.6 \pm 0.46 (4)	0.0 \pm 0.01 (4)	2.5 \pm 0.81 (4)	0.0 \pm 0.01 (4)	64.2 \pm 4.9 (4)	32.7 \pm 30.7 (2)	10.6 \pm 4.7 (4)	35.8 \pm 24.2 (2)		
<i>E. radiata</i> HHAP832	1.3 \pm 0.31 (4)	0.0 \pm 0.00 (4)	1.6 \pm 0.40 (4)	0.0 \pm 0.00 (4)	69.6 \pm 5.6 (4)	24.3 \pm 22.3 (2)	6.0 \pm 3.5 (4)	40.0 \pm 20.0 (2)		
<i>E. radiata</i> HHAP731	1.5 \pm 0.24 (4)	0.0 \pm 0.03 (4)	2.1 \pm 0.60 (4)	0.0 \pm 0.03 (4)	63.6 \pm 7.9 (4)	30.7 \pm 18.0 (3)	18.1 \pm 9.6 (4)	28.8 \pm 14.5 (3)		
<i>E. radiata</i> HHAP830	1.6 \pm 0.22 (4)	0.0 \pm 0.00 (4)	2.3 \pm 0.56 (4)	0.0 \pm 0.00 (4)	71.1 \pm 5.8 (4)	17.5 (1)	9.1 \pm 2.2 (4)	15.0 (1)		

^AAnalysis used a quasibinomial generalised linear model.

^BPermutation tests were used for these analyses due to violated assumptions with parametric models, and so the test statistics do not have degrees of freedom.

^CA cubed-root transformation was applied to the response variable.

^DA cubed-root transformation was applied to the response variable.

^EThe response variable was arcsin-transformed.

E. acaciiformis, however, was notable for its multi-stemmed habit (an average of 2.3 stems per tree per plot compared with 1.0–1.5 stems per tree per plot for all other combinations of species and landscape position) and low amounts of foliar insect damage compared with the other lowland plantings of eucalypts (34.7–51.3%). *E. dalrympleana* also performed moderately well in plantings on the flat, generally recording lower values but not differing significantly from *E. acaciiformis* in survival (80.1%), average or maximum height (3.4 and 4.6 m, respectively), stem diameter (6.6 cm), basal area (2.92 m²/ha), volume (4.16 m³/ha) or foliage density (51.3%). *C. cunninghamiana* and *E. radiata* performed very poorly on the flat with survival percentages of 14.0–16.3% and average heights per plot of survivors of 1.5–2.2 m after 5 years. Despite their superior performance upslope, *P. radiata* and *E. nitens* on the flat generally did not perform as well as *E. acaciiformis* and *E. dalrympleana* in the same plots. In particular, lowland *E. nitens* survival (24.0%) and basal area (0.62 m²/ha) were significantly less than the values recorded for *E. acaciiformis*.

The difference in tree performance between the upslope plantings and the low-lying plots was stark although the physical separation of the two groups of plots only amounted to a distance of 400–1200 m and just 9 m in elevation. The three species planted in both low-lying and upslope plots performed better upslope (although not always significantly so) in survival percentage, average and maximum height, DBH, basal area, volume and foliage density, as well as suffering less foliar insect attack and no livestock browsing. The principal cause of poor tree survival in the low-lying plots was early frosts in March 2004 when seedlings were 5–7 months old (Reid *et al.* 2005) with only minor subsequent loss of trees. *C. cunninghamiana*, *E. nitens* and *E. radiata* were all severely affected in the two lowest lying plots (A8 and B8), whereas *E. acaciiformis* proved tolerant and *E. dalrympleana* and *P. radiata* survival was intermediate. Frost and waterlogging are the two main limitations to the establishment and early growth of trees on the Northern Tablelands (Reid *et al.* 1997; Carr 2009). The high altitude and frequent dry winters often generate severe frosts, with relatively small changes in distance and elevation and minor variations in local topography markedly affecting cold air drainage and frost severity (Thompson 1969; Lodge and Whalley 1989). Moderate rainfall, low temperatures due to the elevation, and duplex and gradational soils with clay B horizons over most of the region lead to waterlogging in lower parts of the landscape with winter rain. These factors conspire to produce periodically stressful conditions low in the landscape for tree species not adapted to severe frost and prolonged waterlogging.

In the present experiment, the impact of frost and waterlogging on most of the eucalypt plantings on the flat was exacerbated by higher levels of insect attack than in upslope plantings. Many studies have demonstrated increased levels of insect herbivory on plants growing under stressful conditions, although the mechanisms are often unclear (Stone and Birk 2001). In both natural stands of mature *E. camaldulensis* and young plantation *E. dunnii*, slow growing trees (due to drought stress, and poor nutrition, weeds and waterlogging, respectively), suffered high levels of insect foliar damage (Stone and Bacon 1994; Stone and Birk 2001).

Implications for species selection in on-farm plantings

Based on the results of this trial, *P. radiata* is the most promising commercial timber species near Armidale. *P. radiata* was first planted in the region in the early 20th century with commercial plantations established at Nundle and near Glen Innes in the 1920s and at Nowendoc and Riamukka in the 1970s (Johnson *et al.* 2008). These plantations are the basis for a small softwood timber industry on the Northern Tablelands (Thompson 1997). A local family also produces and mills *P. radiata* on-farm near Kentucky (Taylor and Taylor 2004). Despite problems with fungal needle blight (*Dothistroma*) infection in northern NSW (FCNSW 1987; Ades and Simpson 1990) and occasional hailstorm damage and subsequent tip blight disease (*Diplodia pinea*) in the Armidale and Nundle regions, *P. radiata* is suited to local conditions and could be planted more widely on-farm for commercial timber production. The poor survival (17–69%) and growth (average height 2.4–3.1 m after 5 years) of *P. radiata* in the two lowest-lying plots and reduced growth in all lowland plots compared with upslope underscore the importance of planting *P. radiata* in higher parts of the landscape away from frost and waterlogging (Carr 2009). Although *P. radiata* is considered by some to be an exotic ‘commercial weed’ (Miles *et al.* 2009) and discriminated against on environmental grounds (Cremer 1990), local studies indicate that avian diversity in on-farm plantings of *P. radiata* is comparable to that in scattered eucalypts in pasture (Reid *et al.* 2006).

E. nitens has recently been established in commercial plantations around Walcha on the Northern Tablelands (H. Harris, pers. comm.) and is commonly planted in small-scale plantations in NSW, Victoria and Tasmania (Herbohn *et al.* 2008). The natural distribution of *E. nitens* includes the high-rainfall, eastern escarpment of the Northern Tablelands near Ebor (Shepherd *et al.* 1976). Successful trials have been conducted by Forests NSW near Nundle (Thompson 1997), by Greening Australia in a eucalypt elimination trial near Ebor (Carr 2009) and at the University of New England. Given the good establishment (82%), relative immunity to insects (12% foliar insect damage), rapid growth (average and maximum height, 6.2 and 8.8 m, respectively, after 5 years) and straight single-stemmed form of unselected material in upslope plots in this trial, *E. nitens* could be more widely planted in the region.

Given that the climate of the first 5 years of this trial (2003–08) included some of the driest periods on record in the region, and that *E. nitens* performed best in upslope, free-draining plots, young stands of the species are unlikely to suffer drought stress in the central Northern Tablelands, which has an 800-mm mean annual rainfall currently. However, there are two reasons to proceed cautiously. First, *E. nitens* in the present trial has probably yet to achieve maximum productivity, so it is possible that older stands of the species in this central part of the east–west rainfall gradient across the Northern Tablelands could exploit all the available soil water in future droughts, resulting in reduced growth or mortality. The second cause for caution concerns the relative susceptibility of *E. nitens* to defoliating insects in the pasture environment. In low-lying plots in this trial, *E. nitens* performed poorly due to sensitivity to frost, possible waterlogging and considerable insect canopy damage. The Northern Tablelands is notorious for the dieback of pasture eucalypts due to chronic insect attack (Ohmart and Edwards

1991; Lowman and Heatwole 1992; Reid and Landsberg 2000; Nadolny 2008). A wide variety of herbivorous insects is implicated, such as scarab and chrysomelid beetle adults and larvae, scale, psyllids, the larvae of sawflies, autumn cup and emperor gum moth, and so on, with insect numbers building up in seasons, years and sequences of years of above-average rainfall. Since the first 5 years of this trial were generally dry, *E. nitens* has not yet been exposed to severe defoliating insect pressure. Its susceptibility is demonstrated by the substantial insect damage sustained by trees in low-lying plots.

E. caliginosa matched *P. radiata* in maximum height in upslope plots, but did not perform as well in survival, average height, stem diameter, basal area, stem volume or foliage density. *E. caliginosa* also suffered moderate insect damage, unlike *P. radiata*. *E. caliginosa* is unlikely to be developed for commercial planting in the region for the foreseeable future, despite the fact that local stringybarks (especially *E. laevopinea*, *E. caliginosa* and *E. macroryncha*) are among the most widely exploited native hardwoods in the region for timber (Thompson 1997). Stringybarks (subgenus *Monocalyptus*) typically exhibit slower growth rates and survival compared with eucalypts in the subgenus *Symphyomyrtus* (e.g. Noble 1989; *E. caliginosa* vs *E. nitens* in the present trial; *E. laevopinea* vs *E. viminalis* in a multi-site stratification trial in the Armidale region, Carr 2009). Moreover, there is a large, untapped, native-forest resource of stringybark timber on private land in the region (32 Mt within 100 km of Armidale; Wall 1997). It would be more sensible to manage the existing stringybark forest on private land for timber than developing a plantation resource of the same.

For shade and shelter plantings in low-lying positions in Northern Tablelands pastures, *E. acaciiformis* was the superior species in this trial. It exhibited moderately good survival (75%), moderate growth (average height 3.5 m), modest basal area (5.9 m²/ha) and stem volume (8.8 m³/ha) after 5 years, a shrub-like multiple-stemmed habit, dense foliage (76%), resistance to foliar insect attack, and retention of foliage to near ground level (Fig. 1) in low-lying plots prone to frost and waterlogging. This result parallels the experience of Harnham Landcare Group members on nearby properties (Chris Eveleigh and Jon Taylor, pers. comm.). *E. acaciiformis* is one of very few



Fig. 1. *Eucalyptus acaciiformis* after 18 months. Note the multi-stemmed habit and dense foliage relatively free of insect attack all the way to the ground.

eucalypts able to withstand frost, waterlogging and heavy insect pressure in low-lying pastures in the region. *E. dalrympleana* was the best of the remaining species in low-lying plots, not varying significantly from *E. acaciiformis* in performance in any response variable and with marginally higher survival (80%).

Although *C. cunninghamiana* is often recommended as a potential timber species (e.g. Bird *et al.* 1996; Bonney 1997), no trees survived in the two lowest-lying plots (A8 and B8) to which livestock did not have access at any stage. The indifferent establishment of *C. cunninghamiana* due to frost sensitivity has been recorded elsewhere in the region (Carr 2009) and suggests that the species should not be planted in frost-prone sites despite a presumed tolerance to waterlogging. The poor establishment and growth of the trees that did survive frost in the two remaining lowland plots were probably an artefact of selective browsing of the nitrogen-rich foliage by livestock that gained access to these plots briefly.

E. radiata performance

E. radiata was least impressive of the four species planted in upland plots, but achieved good survival (79%) and moderate growth (average height 3.2 m), stem diameter (5.2 cm) and foliage density (69%) after 5 years, averaged over all seed lots. However, basal area and volume of *E. radiata* in upland plots was poor (1.4 and 2.04 m²/ha, respectively). The species failed in low-lying plots, with only 14% survival at the end of 5 years, and with the few survivors having an average height and stem diameter of just 1.5 m and 3.5 cm, respectively, low foliage density and suffering high insect attack. No significant variation among seed lots was recorded in any response variable, but Lot5 generally performed better than the others. Although a commercial plantation has been established near Bendemeer on the Northern Tablelands for medicinal oil production (Doran *et al.* 2005), our results demonstrate that the high cineole-yielding seed lots of the species tested are sensitive to landscape position. The species should only be planted in upslope positions in the region, and seed lots and provenances with demonstrably greater survival potential should be selected.

Conclusions

Although the Cicerone Project's farm forestry trial has decades to run before long-term survival and growth are known, the early results are consistent with those of commercial plantation forestry and farm tree plantings in the region. *P. radiata* can be recommended for commercial tree establishment for timber production in pasture on the Northern Tablelands, similar to the upper parts of the Cicerone farmlet landscape. Similar advice could be extended for *E. nitens*, but growers should be cautious about the water requirements of mature plantations in drier areas and the performance of the species in years of high insect pressure. *E. acaciiformis* should be planted more widely for shade and shelter in low-lying pastures in the region. *E. dalrympleana* may be included in low-lying biodiversity and amenity plantings if good establishment but only moderate growth and resistance to defoliating insects are required. If high cineole-yielding seed lots of *E. radiata* are established for oil production, plantings should be high in the landscape where modest growth can be anticipated. Given the debate over the

merits of exotic versus native species (Harrison *et al.* 2005; Sangha and Jalota 2005) and local provenance vs high-quality, genetically diverse germplasm for restoration plantings (Broadhurst *et al.* 2008; Krauss *et al.* 2010–11), it is worth noting that among the four best performing species in this study were one exotic species (*P. radiata*), two regionally occurring native (but non-local) species (*E. acaciiformis* and *E. nitens*), and one locally occurring native (*E. dalrympleana*). In highly modified environments, generalities about the value to restoration of germplasm of different origins may often be irrelevant.

Acknowledgements

Our thanks go to the Harnham Landcare Group for helping to defray the costs of the trees. The advice from Bob Marchant regarding the location of tree plots with respect to grazing paddocks is gratefully acknowledged.

Justin Hoad was employed by the Cicerone Project, which was supported by Australian Wool Innovation. We are grateful to Chris Eveleigh for initial tree selection advice, Hugh Harris for *E. radiata* seed, and to Caroline Gaden for administrative and technical support of the Cicerone Project and this trial.

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