Designing food and habitat trees for urban koalas: identifying short ecotypes of *Corymbia intermedia*

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Abstract. The eucalypt trees eaten by koalas are generally tall but urban landholders prefer to plant shorter trees that pose less danger of limbs falling from a great height or damaging powerlines. We aimed to develop shorter eucalypt trees to provide food and shelter for koalas and other fauna in urban areas. We identified short ecotypes of *Corymbia intermedia* growing naturally on exposed coastal headlands, and we tested whether their seedlings were shorter than the seedlings of nearby tall ecotypes when planted in cultivation. Trees raised from the short ecotypes were 22–43% shorter than trees raised from the tall ecotypes, being around 5–7 m tall rather than 8–12 m tall after 8 years. This demonstrated that there was a genetic basis for the short stature of *C. intermedia* trees on coastal headlands. These shorter *C. intermedia* trees could be valuable food and habitat trees for urban koalas and other fauna.

Additional keywords: *Corymbia*, *Eucalyptus*, koala, *Phascolarctos cinereus*, street trees, tree height, urban fauna.

Introduction

The koala (*Phascolarctos cinereus*) is an iconic marsupial under threat in eastern Australia from habitat fragmentation, urban development, car strikes, dog attacks, fire, drought, disease and inbreeding (Lee *et al.* 2010; Seabrook *et al.* 2014; McAlpine *et al*. 2015; Adams-Hosking *et al*. 2016). Local councils have recognised a need to revegetate urban and peri-urban areas with eucalypt trees that offer food and shelter for koalas and which provide vegetation corridors between larger tracts of native forest (de Oliveira *et al*. 2014). Most of the tree species that are eaten by koalas are tall but many householders and utility service providers prefer the planting of smaller trees that pose less risk of large branches falling from a great height or damaging infrastructure such as power-lines and pavements (Williams 2002; Kendal *et al.* 2012; Kirkpatrick *et al.* 2012; Mullaney *et al*. 2015). Koalas in mature forests prefer tall trees especially on hot days (White 1999; Sullivan *et al.* 2003; Matthews *et al.* 2007; Moore *et al.* 2010). However, many koalas inhabit small urban trees in backyards, frontyards and along streets, young trees in rehabilitated landscapes, and isolated paddock trees (White 1999; Sullivan *et al.* 2004; de Oliveira *et al*. 2014).

We have been developing shorter eucalypt trees for planting in urban areas. One of our aims was to develop short trees by grafting scions from tall species that are eaten by koalas onto rootstocks from related short species. However, interspecific grafted trees either (a) survived well but grew tall or (b) were short but had high mortality (Trueman *et al*. 2014). Another aim has been to identify short populations of otherwise-tall eucalypt species and assess whether their progeny remain short in cultivation. Short ecotypes of *Eucalyptus globulus* have been identified previously on coastal headlands in temperate southern Australia (Jordan *et al*., 2000; Foster *et al*., 2007). Short plants on exposed coastal sites are generally assumed to be environmental variants although they, in fact, may often be genetic variants of a species (Jordan *et al*., 2000; Foster *et al*., 2007; O'Brien *et al*. 2010). *E. globulus* seedling progeny from short trees on coastal headlands grow more slowly in cultivation than seedlings from tall inland ecotypes, indicating a genetic basis for the height of the short ecotypes on exposed headlands (Jordan *et al*., 2000).

In this study, we identified short ecotypes of a koala-food species, *Corymbia intermedia* (Tucker *et al*., 2007; Callaghan *et al*., 2011), growing on exposed coastal headlands in subtropical eastern Australia. We collected seed from each population and compared the height in cultivation of seedlings from the short coastal populations with the height of seedlings from nearby tall inland populations. The results of the study may help us to identify shorter eucalypt trees that are suitable for planting in urban areas.

Materials and methods

We identified natural populations of mature reproductive trees of *Corymbia intermedia* (pink bloodwood) on the Sunshine Coast, Queensland, Australia. Short populations were found in forest on coastal headlands at George Watson Park, Moffatt Head, and at Wickham Point, Caloundra Head (Fig.1, Table 1). Tall populations were found in forest at Sharyn Bonney Reserve and Ben Bennett Botanical Park, Caloundra, approximately 2.5–3.5 km inland from the short populations (Fig. 1, Table 1). Henceforth, the four populations are named ‘Watson’, ‘Wickham’, ‘Bonney’ and ‘Bennett’, respectively. The height and basal trunk diameter of five trees per population were recorded between July and October 2007 (Table 1). Seeds were collected from each of these 20 trees.

We sowed seeds from each of the 20 trees into individual 4.5-L trays in January 2008. The germination medium consisted of 100% shredded pine bark with 3 kg of 8-9 month slow release Osmocote^{TM} fertiliser (Scotts International, Heerlen, The Netherlands), 3 kg lime (Unimin, Lilydale, VIC), 1 kg gypsum (Queensland Organics, Narangba, QLD), 1 kg Micromax^{R} micronutrients (Scotts Australia, Baulkham Hills, NSW) and 1 kg Hydroflow^{TM}

wetting agent (Scotts Australia, Baulkham Hills, NSW) incorporated per m^3 (Trueman *et al*. 2014). Seeds were covered with a thin layer of vermiculite and the 20 trays were placed in a random arrangement under mist irrigation in a translucent white polyethylene tunnelhouse in Gympie (26°09'S, 152°38'E). Mist irrigation was provided for 1 min every hour from 0600 to 1800 H. We transplanted seedlings upon emergence of the second pair of leaves into 70-mL tubes filled with propagation medium consisting of a 75/25 (v/v) mixture of shredded pine bark and perlite that contained the same additives used in the germination medium (Trueman *et al*. 2013a,b,c). Each seedling was tagged with an individual number that could be related back to its parent tree and natural population. The seedlings were placed on outdoor benches under 50%-shade cloth for 2 weeks, and then moved to full sunlight. Watering was provided by overhead sprinklers for 15 min twice a day.

We planted *C. intermedia* trees in May 2008 at Chancellor State College (26°42'S, 153°04'E), Sippy Downs. The site has a low-fertility coastal duplex soil with sand over clay. The seedlings, approximately 30-cm height, were allocated randomly and planted in three rows around the western and northern perimeters of the school campus at a spacing of 3.0 m × 2.5 m (inter-row × within-row). Tree holes, 300-mm diameter and 400-mm depth, were excavated 1 d prior to planting, and the trees were provided with a shallow covering (*c*. 20-mm depth) of mulch after planting.

We also planted *C. intermedia* tree in July 2008 at Kybong (26°19'S, 152°42'E) on a site to be developed as public parkland. These seedlings were allocated randomly and planted in gaps where seedlings had died after a May 2008 planting of other *Corymbia* and *Eucalyptus* species (see Trueman *et al*. 2014). Trees at this site were planted at a spacing of 4.5 × 3.0 m in cultivated rows, without mulching, on a high-fertility red volcanic ferrosol soil.

The number of replicate trees per natural population ranged from 8–14, depending on the population and planting site. The identity of each planted seedling was maintained from planting to tree measurement by recording the seedling tag numbers on a map. Tree survival and height were measured at 8 years after planting. Survival data were analysed by binomial tests. Height data were analysed by ANOVA, followed by least significant difference (l.s.d.) tests where significant differences among four population means within each study site were detected by ANOVA. Data for individual trees within natural populations were pooled because of low replication and because significant differences were not detected among trees within populations. Means are reported with standard errors and treatment differences were regarded as significant at $P < 0.05$.

Results and discussion

Field survival of cultivated *C. intermedia* trees differed among the natural populations although there was no consistent difference in survival between trees from short and tall populations (Table 2). Trees derived from one of the tall natural populations had higher survival, 91% (Bennett), than trees from all of the other natural populations, 50-64% (Watson, Wickham and Bonney), when planted on the low-fertility coastal plain soil at Sippy Downs. Survival did not differ significantly between the short and tall natural populations on the high-fertility volcanic soil at Kybong, although survival for trees from one short population, 85% (Watson), was significantly higher than for trees from the other short population, 50% (Wickham). Caution is warranted in interpreting tree survival at Sippy Downs because this site was part of a school campus where the seedlings were subjected to a high volume of pedestrian traffic. Nonetheless, the long-term survival of short-population *C. intermedia* trees across the two different planting sites (50-85%) indicates that they are suitable for horticultural plantings beyond their natural location on coastal headlands.

Seedling progeny from the short *C. intermedia* populations were shorter than seedlings derived from nearby tall populations, both at Sippy Downs (Fig. 2*a*) and at Kybong (Fig. 2*b*).

Tree heights of the short-population progeny at Sippy Downs were 6.11 ± 0.47 m (Watson) and 5.16 ± 0.44 m (Wickham), equating to reductions of 22–40% when compared with tall-population heights of 8.61 ± 0.61 m (Bonney) and 7.87 ± 0.41 m (Bennett). Tree heights of the short-population progeny planted at Kybong were 6.82 ± 0.56 m (Watson) and 7.41 ± 0.68 m (Wickham). This equated to reductions of 33–43% when compared with tall-population heights of 11.95 ± 1.55 m (Bonney) and 11.03 ± 0.53 m (Bennett) at the same planting site. These results indicate that there is a genetic basis to the height of short *C. intermedia* ecotypes on exposed coastal headlands even though they are separated by as little as 2.5 km from the tall ecotypes. The selection pressures that favour the survival and reproduction of these short ecotypes on headlands are unclear although they may include reduced vulnerability to soil salinity and foliage damage from the high winds and salt spray that are typical of exposed coastal sites (Jordan *et al*. 2000; Griffiths 2006, Yoko-o and Tokeshi 2011).

The differences in height that we observed between short coastal and nearby tall ecotypes of *C. intermedia* in natural populations are comparable to those observed previously in *E. globulus* (Jordan *et al*. 2000). The *C. intermedia* trees on Moffatt Head and Caloundra Head were approximately 6–7 m tall whereas nearby tall ecotypes were approximately 19–20 m tall. This was despite the short trees at Moffatt Head having similar trunk diameters (≥ 40 cm) to trees in the two tall populations (Table 1). Mature *E. globulus* trees on exposed headlands at Cape Tourville, Tasmania, were 3–4 m tall whereas trees only 1.5 km inland were 25 m tall (Jordan *et al*. 2000). The short *E. globulus* ecotypes possessed about 22% less trunk diameter after 5 years in cultivation than did tall ecotypes (Jordan *et al*. 2000), similar to the reductions of 22–43% in tree height that we observed with short *C. intermedia* ecotypes after 8 years in cultivation. Microsatellite and chloroplast DNA analyses revealed that the short *E. globulus* ecotypes were genetically differentiated from tall ecotypes (Foster *et al*. 2007). This differentiation appeared to be maintained by differences in flowering time and lack of pollen dispersal from the tall to short ecotypes (Foster *et al*. 2007). Flowering phenology and population genetics have not been assessed in the *C. intermedia* populations but, unlike the *E. globulus* ecotypes at Cape Tourville, the short *C. intermedia* ecotypes at Moffatt Head and Caloundra Head are separated from the tall ecotypes by extensive urban development that may limit the opportunities for pollen and seed dispersal.

The short *C. intermedia* ecotypes reached about the same height after 8 years of cultivation as their mature parent trees that are 6–7 m tall on coastal headlands. We do not consider them to be dwarf trees in the way that coastal headland ecotypes of *E. globulus* (3–4 m tall) and *Banksia spinulosa* (<1 m tall) have been described (Foster *et al*. 2007; O'Brien *et al*. 2010). However, the short-ecotype *C. intermedia* trees were 22–43% shorter in cultivation than tall-ecotype trees, being around 5–7 m tall rather than 8–12 m tall. They were also much shorter than most other koala-food species of *Corymbia* and *Eucalyptus* (9–14 m tall after 5 years) that were planted at the same high-fertility site at Kybong (Trueman *et al*. 2014).

The value of short-ecotype *C. intermedia* trees for urban koala food and habitat will depend partly on the palatability of their foliage, which can vary within eucalypt species (Lawler *et al*., 1998; Moore *et al*., 2010). We have provided foliage from the cultivated short-ecotype and tall-ecotype trees (Fig. 3a) as koala fodder to the Wildlife HQ zoo (Nambour, QLD). Foliage from both ecotypes is consumed eagerly by koalas (Fig. 3b-f). This study, therefore, demonstrates the potential of short-ecotype *C. intermedia* trees for planting in streets, gardens and parklands as food and habitat for koalas in urban areas. The planting of short eucalypt trees in urban areas is only one dimension in a multi-dimensional issue for koalas that are under threat from habitat fragmentation, urban development, car strikes, dog attacks, fire, drought, disease and inbreeding (Lee *et al.* 2010; Seabrook *et al.* 2014; McAlpine *et al*. 2015; Adams-Hosking *et al*. 2016). However, the planting of small eucalypt trees in urban areas where the planting of tall eucalypts would be discouraged will provide additional food and shelter for urban koalas that transit between larger tracts of forest (de Oliveira *et al*. 2014). The benefits of additional eucalypt trees in urban areas extend beyond koalas because eucalypt trees also provide food, habitat and movement corridors for a wide range of less-iconic native fauna.

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Conflicts of interest

The authors declare no conflicts of interest.

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Table 1. Locations, heights and basal trunk diameters of *Corymbia intermedia* trees in short and tall natural populations

Population	Tree type	Location	Tree height (m)	Trunk diameter (cm)
Watson	Short	George Watson Park, Moffatt Head (26°47'S, 153°08'E)	7.2 ± 0.2	44.6 ± 6.8
Wickham	Short	Wickham Point, Caloundra Head (26°48'S, 153°09'E)	5.7 ± 0.4	17.2 ± 0.9
Bonney	Tall	Sharyn Bonney Reserve, Caloundra (26°47'S, 153°06'E)	19.0 ± 1.0	40.0 ± 3.1
Bennett	Tall	Ben Bennett Botanical Park, Caloundra (26°47'S, 153°07'E)	20.2 ± 1.0	57.8 ± 6.2

Means are provided with standard errors (n = 5)

Table 2. Survival of *Corymbia intermedia* trees from short and tall natural populations at 8 years after planting at Sippy Downs or Kybong

Population	Tree type	Survival (%)	
		Sippy Downs	Kybong
Watson	Short	50b	85a
Wickham	Short	50b	50b
Bonney	Tall	64b	67ab
Bennett	Tall	91a	77ab

Means among the natural populations with different letters within each planting site are significantly different (binomial tests, $P < 0.05$, n = 8–14).

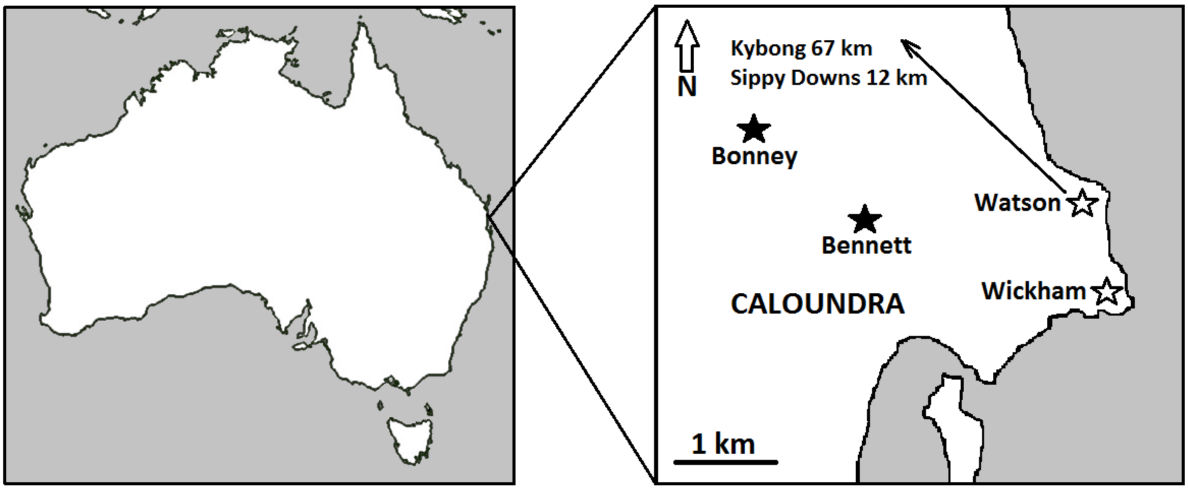

Figure 1. Locations of *Corymbia intermedia* trees in short populations (Watson and Wickham: open symbols) and tall populations (Bonney and Bennett: closed symbols) at Caloundra, Sunshine Coast, Australia. Locations of the tree planting sites at Sippy Downs and Kybong are indicated by an arrow.

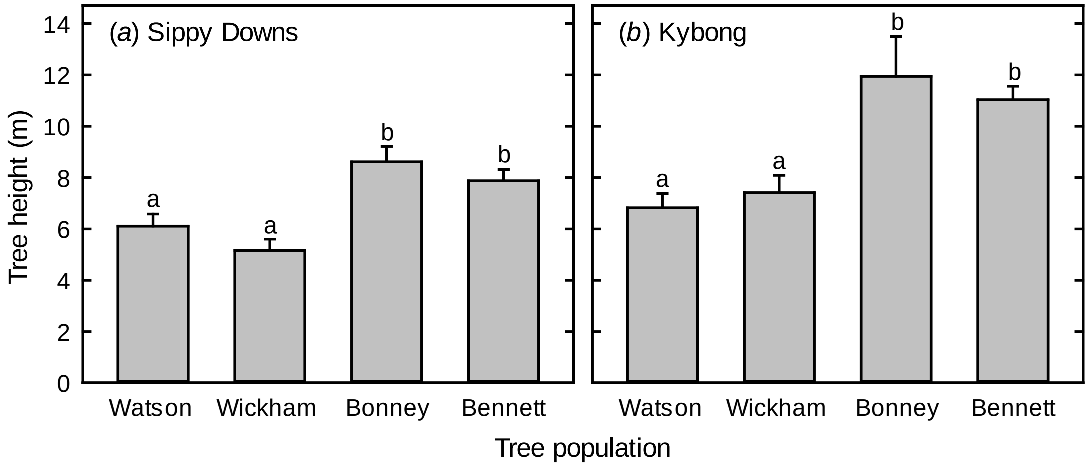

Figure 2. Height of *Corymbia intermedia* trees at (*a*) low-fertility Sippy Downs and (*b*) high-fertility Kybong at 8 years after planting. Means among the four tree populations (Watson, Wickham, Bonney and Bennett) with different letters within each site are significantly different (ANOVA and l.s.d. test, $P < 0.05$, n = 4–11).

Figure 3. (*a*) A short-ecotype *Corymbia intermedia* tree (foreground), approximately 6 m tall at Sippy Downs at 8 years after planting, and (*b*-*f*) koalas consuming the foliage of cultivated short-ecotype *C. intermedia* trees.