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The potential for gene flow from exotic eucalypt plantations into Australia's rare native eucalypts

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ABSTRACT

Hybridisation through pollen dispersal from exotic plants is increasingly recognised as a threat to the genetic integrity of native plant populations. Its genetic impact can be greater in rare taxa, due to their vulnerability to pollen swamping by more abundant congeners. We assessed the likelihood of pollen dispersal from exotic eucalypt plantations into all of Australia's rare native eucalypts, and conducted a case study of *Eucalyptus perriniana*, which is rare in Tasmania. The Australia-wide study involved spatial analyses of the locations for each rare species superimposed on distributions of eucalypt plantations, which were combined with known taxonomically based reproductive barriers. Of the 74 nationally listed rare eucalypt taxa, 22 had locations within 10 km of plantations of the same genus, and eight were within 1 km. These eight proximal taxa are considered priorities for monitoring. In the most extreme case, 30% of point locations originating from herbarium records and field surveys for *Eucalyptus conglomerata* were within 1 km of exotic plantations. In the case study, *E. perriniana* revealed considerable reproductive compatibility with adjacent recently established *Eucalyptus nitens* plantations. However, F_1 hybridisation between these species was limited, with 0.2% of the 18,625 seedlings grown from 100 single-tree open-pollinated seedlots being hybrids. For now, the probability of exotic gene flow into *E. perriniana* appears to be low, however this probability is likely to increase as more *E. nitens* flowers in the surrounding landscape. These studies suggest that understanding the breeding system and biology of these populations may reveal surprising resistance to such exotic hybridisation as well as identifying high risk situations to focus conservation management.

1. Introduction

Hybridisation between species or between naturally allopatric populations is now recognised as being an important contributor to the evolution (Abbott et al., 2003; Ellstrand and Schierenbeck, 2000) and invasion (Ellstrand et al., 2010; Gaskin and Schaal, 2002; Vila et al., 2000) of many exotic plant species. Movement of pollen and its potential genetic and ecological consequences became a public concern following the deployment of genetically modified (GM) crops, as escapes of transgenes into non-transgenic populations were reported (Stewart et al., 2003). These studies highlighted the importance of considering pollen movement and its impacts more generally (Ellstrand, 1992; Ellstrand and Elam, 1993). Gene flow from non-GM crops or exotic species into native populations through hybridisation and introgression has been recognised as posing a risk to the genetic integrity and survival of "pure" species populations (Ellstrand, 1992; Rhymer and Simberloff, 1996; Wolf et al., 2001). These risks have the potential to be higher in the case of rare species and small populations, due to their vulnerability to reproductive swamping (i.e. source/sink effects, Ellstrand and Elam, 1993; Field et al., 2009; Levin et al., 1996; Wolf et al., 2001) and sensitivity to compounding adverse environmental conditions (Rhymer, 2008).

Eucalypts represent a central component of the Australian biota, being the dominant tree in the majority of non-arid woodland and forest communities (Williams and Woinarski, 1997). There are nearly 900 eucalypt taxa (CPBR, 2006), which are endemic to Australia and its surrounding islands. Within these, 74 taxa are currently listed as endangered or vulnerable at the national level in Australia and require special attention. A notable characteristic of eucalypts is their propensity for interspecific hybridisation (Potts and Wiltshire, 1997). Under natural circumstances eucalypts are often observed to hybridise (Griffin et al., 1988; Potts and Wiltshire, 1997), however, the degree to which this occurs is limited by pre-

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mating barriers such as spatial isolation and flowering asynchrony (Keatley et al., 2004; Potts and Wiltshire, 1997), and post-mating crossing-incompatibilities. The latter prevents successful hybridisation between the three genera of eucalypts (*Angophora*, *Corymbia*, and *Eucalyptus*) and also between the major subgenera within *Eucalyptus* (Griffin et al., 1988; Potts et al., 2003).

At least eight eucalypt species and a few artificial hybrids are being deployed in industrial hardwood plantations in Australia (National Forest Inventory, 2006). This plantation estate has expanded dramatically over the last two decades, and now covers nearly 1 million ha in Australia (950,000 ha, Gavran and Parsons, 2009). Its expansion is likely to continue due to increasing public pressure to reduce native forest harvesting, reduce the Australian trade deficit in forest products and to develop carbon off-set industries (National Forest Inventory, 2006). Due to the often weak barriers to hybridisation within eucalypts, there is concern over the potential for pollen-mediated gene flow from plantations into native eucalypt populations (Kanowski et al., 2005; Potts et al., 2003; Salt et al., 2005; Strauss, 2001; Wardell-Johnson et al., 1997). This concern is based on the fact that genetic material used for stocking plantations is typically established well out of its native range, as locally exotic species, hybrids, provenances or genotypes (Barbour et al., 2008a; Potts et al., 2003).

Considerable work has been conducted to assess the potential for exotic gene flow from the major temperate plantation eucalypts in Australia, *Eucalyptus globulus* and *Eucalyptus nitens*. This work has demonstrated that F_1 hybridisation involving plantations and their adjacent native species can occur (Barbour et al., 2008b, 2003, 2005a,b, 2006b, 2002) and that F_1 hybrid seedlings are establishing in the wild at some locations (Barbour et al., 2008b, 2003). In addition, work in the subtropical and tropical regions of Australia has identified a potential for such gene flow (Barbour et al., 2008a; Kanowski et al., 2005). An important aspect of assessing the off-site risks from planting *Eucalyptus* that has not been addressed is the likelihood of exotic gene flow to the rare eucalypt species of Australia.

The aim of this study was to assess the likelihood of pollen-mediated gene flow from eucalypt plantations into all nationally listed endangered or vulnerable (herein referred to as rare) eucalypt species of Australia to better focus resources to the protection of species most at risk. This assessment was conducted through the integration of spatial analyses of the proximity of plantations to each native species, and the knowledge of the reproductive barriers that exist amongst them. Following this, a detailed case study was conducted into the likelihood of exotic gene flow into a rare Tasmanian species, *Eucalyptus perriniana*, from surrounding *E. nitens* plantations, by assessing levels of F_1 hybridisation between the two species and their reproductive biology.

2. Materials and methods

2.1. Spatial assessment

All 74 eucalypt species or subspecies classified as endangered or vulnerable in 2009 by the Australian Government (Department of the Environment, Water, Heritage and the Arts, www.deh.gov.au/cgi-bin/sprat/public/sprat.pl) were assessed for their spatial distribution relative to eucalypt plantations. Three species on the list, *Eucalyptus aquatica*, *Eucalyptus olivacea* and "*Eucalyptus* sp. Howes Swamp Creek" were not included in the analyses as they were no longer regarded as legitimate taxa and therefore could not be cross-referenced with other resources (e.g. CPBR, 2006). Point location data for each species were provided by the relevant state agencies (see "Acknowledgements"). These data point locations originated from herbarium records and field surveys, and their number per species ranged from 1 to 357. Some populations were represented by more than one point location, but on average we assume that the number of point locations is consistent with the size of a population and the number of populations for a species. Outliers that fell well outside the distributional range of each species (as described in CPBR, 2006) were removed from the analyses. The original data was recorded in a number of different projections and datums, and was projected to GDA94. The precision of the original collection location also varied, but the majority of records had a locational accuracy of better than 100 m.

The distribution of eucalypt plantations throughout Australia current to 2008, was provided as GIS shape files by the National Forest Inventory. These files delineated the taxa used in plantations at the genus level only. According to the National Forest Inventory (2006), eucalypt plantations in Australia are typically established using *E. globulus* (subgenus *Symphyomyrtus*, 64% of the total area), *E. nitens* (*Symphyomyrtus*, 20%), *Eucalyptus pilularis* (subgenus *Eucalyptus*) and *Eucalyptus grandis* (*Symphyomyrtus*) (combined at 4%), *Eucalyptus dunnii* (*Symphyomyrtus*, 3%), *Corymbia* (species and hybrids from section *Politaria*, 2%) and other minor taxa such as *Eucalyptus cladocalyx* (*Symphyomyrtus*), *Eucalyptus occidentalis* (*Symphyomyrtus*) and *Eucalyptus cloëziana* (*Idiogenes*) (6%; National Forest Inventory, 2006; see Fig. 1). The subgeneric classification within genus *Eucalyptus* follows Brooker (2000). Spatial analysis was conducted using ESRI ArcGIS 9.2 software. Eucalypt plantations were extracted from the National Forest Inventory raster, and converted to polygons for further analysis. The shortest distance of each point location to a plantation of the same genus or subgenus was calculated, as was the area of that plantation. Buffers of 10 km, 1 km and 100 m width were generated around plantation polygons, and the proportion of point locations of each species that fell within the buffers was calculated.

2.2. Field and glasshouse-based work assessing E. perriniana

The case study focusing on *E. perriniana* was conducted using the Strickland population in southern Tasmania (42°21′S, 146°39′E, see Rathbone et al., 2007). *E. perriniana* (subgenus *Symphyomyrtus*) is not listed as a threatened or vulnerable species at the national level, but is listed as rare in Tasmania under the Threatened Species Protection Act (1995). In Tasmania, this species consists of three small populations with an estimated total number of individuals of approximately 1000, the largest of these populations being at Strickland (Rathbone et al., 2007; Wiltshire and Reid, 1987). The conservation value of these populations has increased following recent genetic analyses showing the Tasmanian populations of *E. perriniana* to be distinct from the mainland populations (Rathbone et al., 2007). While populations of some rare eucalypt species are genetically depauperate, this does not appear to be the case for *E. perriniana* as nuclear microsatellite diversity within its populations is comparable to that observed in many widespread eucalypt species (Rathbone et al., 2007).

Recently, a two-stage planting program using *E. nitens* has taken place in the landscape surrounding the Strickland *E. perriniana* population (Fig. 2). *Eucalyptus nitens* is exotic to the island of Tasmania, as it naturally exists as disjunct populations in Victoria and New South Wales (Pederick, 1979). The first planting of *E. nitens* at Strickland took place in 1998, with its closest point to the *E. perriniana* population being 600 m. Following this, further plantings took place in the surrounding landscape (Fig. 2). At the time of the study, the first planting was eight and half years old and had flower buds present and seed capsules from flowering in previous years, while the second stage of plantings was still reproductively immature. As of early 2008, approximately 562 ha of plantations existed within 10 km of the *E. perriniana* Strickland population but no plantation was within 500 m.