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Supplementary material

Can ecological thinning deliver conservation outcomes in high-density river red gum forests? Establishing an adaptive management experiment

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Table S1. Rationales for hypothesised effects of thinning River Red Gum (RRG) forests.

Hypothesis	Rationale for hypothesis	Relevant literature	Monitoring variable	Survey effort
1a. Increased growth and survival rates of retained trees	Retained trees will have faster growth rates, as a result of increased access to resources (water, light, space and nutrients).	Thinning increased growth rates in silvicultural settings; heavier thinning produced a greater response (Schonau and Coetzee 1989; Davis *et al*. 2007; Kariuki 2008), including RRGs (Horner *et al*. 2010).	Tree diameter at breast height over bark (≥10 cm DBHob) (mm)	30 permanently marked trees ≥10 cm diameter at breast height (DBH). Yearly.
	A greater proportion of trees will obtain sufficient resources to complete their lifecycle.	In thinned stands mortality increased for small trees for 1-2 years; but was lower in the longer term (Davis *et al*. 2007; Horner *et al*. 2009, 2010; Kariuki 2008), apparently due to increased water availability (Horner *et al*. 2010).	Live/dead status of trees ≥10 cm DBH	50 trees ≥10 cm DBH. Yearly.
		Likelihood of tree survival is correlated with tree size and stand density, with mortality higher in unthinned than thinned stands (Horner *et al*. 2009, 2010; Kariuki 2008).	Fate of trees ≥80 cm DBH	All ≥80 cm DBH trees in 2 ha plot. 5 yearly.

Hypothesis	Rationale for hypothesis	Relevant literature	Monitoring variable	Survey effort
1b. Increase the number and proportion of trees occurring in large diameter size classes	Retained trees will have increased growth and survival rates, which will increase the recruitment of trees into larger size classes (>60 cm DBH) over time.	Thinned RRG stands had a higher proportion of large trees, higher median and maximum DBH values, than unthinned stands (Horner *et al*. 2010).	Distribution of trees amongst DBH size classes	All trees in ten 0.25 ha plots. 5 yearly.
1c. Increased crown spread and hollow development rates	Retained trees will develop open crown structures with larger lateral branches (rather than tall straight trees), as a result of decreased competition for space and light.	Open, spreading crowns are not developed in high-density stands of trees (Vesk *et al*. 2008).	Opaque crown (m^2)	30 permanently marked trees $\geq$10 cm DBH. 5 yearly.
	Increased lateral branching will lead to increased hollow development rates.	Larger trees with lateral branching tend to develop more hollows (Bennett *et al*. 1994; Thomson *et al*. undated; Vesk *et al*. 2008). Higher densities of hollow-bearing trees occurred in thinned RRG stands (Horner *et al*. 2010).	Number of trees with hollows ($\geq$5 cm entrance)	All hollow bearing trees in 2 ha plot. 5 yearly.
1d. Increased tree canopy health (proportion of potential crown that's live)	Retained trees will increase canopy extent (the proportion of the assessable crown area that supports living tissue; Souter *et al*., 2009), as a result of increased access to water (and other) resources.	RRG trees reduce water demand by shedding leaves (Souter *et al*. 2009; Roberts 2001), and have larger, denser crowns under reduced water stress (Stone and Bacon 1994). Crown expansion is likely in RRGs, as apical dominance is weak (FC NSW 1984; Horner *et al*. 2010).	Tree crown extent (%)	30 permanently marked trees $\geq$10 cm DBH. Yearly.
	Retained trees will have greater numbers of larger leaves in the canopy, as a result of increased access to water (and other) resources.	RRGs under moisture stress have been found to produce significantly smaller and fewer leaves (Stone and Bacon 1994).	Projective foliage cover (remotely sensed)	Remote sensed. Yearly.
	Retained trees will decrease the proportion of dead foliage in the canopy, as a result of increased access to water (and other) resources.	RRGs under reduced water stress have been found to have significantly less dead tissue per shoot (Stone and Bacon 1995).	% of total projective foliage cover that is dead (remotely sensed)	
	Retained trees will increase the area of leaves and stems in the canopy, as a result of increased access to water (and other) resources.	RRGs under reduced water stress have increased: leaf and shoot production, mean leaf size and leaf retention (Stone and Bacon 1995).	Plant Area Index	5 hemispherical photos per 2 ha plot. 5 yearly.
1e. Increased recruitment of tree seedlings in	Increased seedling establishment may result from reduced competition for light,	Competition is one of the primary limitations of seedling establishment for RRGs (Dexter 1978).	Number of seedlings	All seedlings in three 0.04 ha plots. Yearly.

Hypothesis	Rationale for hypothesis	Relevant literature	Monitoring variable	Survey effort
early post-treatment years	space, water and nutrient resources. The process model workshop highlighted uncertainty regarding whether thinning would stimulate a recruitment event (Walshe *et al*. 2011).			
1f. Increased survival of seedlings (<1.3 m) and saplings (> 1.3 m; <10 cm DBH)	Seedling and sapling survival will increase, as a result of reduced competition for light, space, water and nutrient resources.	Seedling survival is 20-30 times greater in the absence of competition from mature RRG trees, (Dexter 1978).	Number of seedlings and number of saplings	All seedlings in three 0.04 ha plots. Yearly
1g. Increased structural diversity of mid- and under-storey strata	The number of understorey strata, and the cover of each stratum, will increase. The understorey of RRG Forest will remain typically patchy with a sparse shrub layer.	The effects of thinning on understorey structure are poorly understood, and have not been studied in RRG forests to our knowledge. Evidence from other ecosystems indicates that increased cover and abundance of understorey strata is plausible (Cummings and Reid 2008; Dwyer *et al*. 2010).	Cover abundance (nearest 5%) and height (m) of dominant plant species in understorey strata	Three 0.04 ha plots. Yearly.
1h. Maintain higher levels of coarse woody debris (45-50 t/ha) in long term	Higher levels of CWD will be maintained over the longer term due to limb fall from larger, branching trees with heavy boughs.	A major source of CWD is boughs produced by large (>100 cm DBH) senescing trees (Vesk *et al*. 2008; Killey *et al*. 2010).	Volume of coarse woody debris (≥10 cm diameter) (tonnes/ha)	Three 0.25 ha plots. 5 Yearly.
1i. Increased heterogeneity in cover and depth of forest litter in the long term	Cover and depth of forest litter will increase as a result of increased canopy vigour.	NRC (2009b) suggested that thinning in RRG forests could reduce deposition rates of leaf litter. However, reduced water stress has been found to increase the vigour of tree canopies, which in turn increased the turnover of canopy foliage and increased deposition rates of litter (Stone and Bacon 1995).	Percent cover of litter and bare ground (%)	60 1m^2 plots. Yearly.
			Depth of litter (mm)	60 1m^2 plots. Yearly.
1j. Decreased persistence of stags in the short term	Persistence of stags (standing dead trees) may decrease due to increased exposure to wind.	Stags were 2-4 times less abundant in heavily thinned stands than control stands in a hardwood plantation in Canada (Graves *et al*. 2000).	Count of stags	All stags in 2 ha plot. Yearly.
1k. Increased fuel and fire risk	Fire risk may increase due to increased levels of fine fuel in the understorey and increased CWD.	The net outcome of thinning on fire risk is poorly understood (NRC 2009b). Litter loads are expected to increase (Stone and Bacon 1995), fine fuels derived from grasses and levels of CWD are likely to be higher in thinned forests (NRC 2009b).	Standard fuel assessment method (Hines *et al*., 2010)	Three 0.04 ha plots. Yearly.

Hypothesis	Rationale for hypothesis	Relevant literature	Monitoring variable	Survey effort
2a. Increase in diversity and increased levels of site utilisation by bat species	The abundance and diversity of bat species utilising the stand will increase as a result of increased habitat heterogeneity and resource availability.	Bats favour large diameter trees and depend on hollows in RRG forests (Tidemann and Flavel 1987; Lumsden *et al*. 2002). Bat activity varies with resource availability (O'Neill and Taylor 1986; M. Pennay pers. comm.). Bat activity may also be affected by shrub and understorey vegetation (O'Neill and Taylor 1986). Bats are known to respond to 15 ha treatments in forests (Law and Chidel 2001).	Bat species richness and diversity; use level.	1 detector per 9 ha plot for 2 nights. Yearly.
2b. Increase in abundance and frequency of foraging activity by woodland bird species	The abundance and diversity of diurnal bird species utilising the stand will increase as a result of increased habitat heterogeneity and resource availability.	Bird species diversity, abundance and breeding increased with RRG stand condition (*sensu* Cunningham *et al*. 2009; Mac Nally *et al*. 2011). Complex vegetation profile is associated with more nest sites, and dense regeneration after clearfelling is associated with low species richness (18 species, compared with other habitats with up to 36 species) (Recher 1991). Different bird species respond differently to stand structure, availability of shrubs etc. (Mac Nally *et al*. 2011). Bird species are likely to benefit from increased CWD density, and have responded at the 1 ha scale to altered CWD (Pickett and Cadenasso 1995; Mac Nally and Horrocks 2007). Area searches for birds are typically 1-3 ha for 10-20 minutes (DEWHA 2010).	Woodland bird species richness and abundance	20 minute searches of 2 ha plot, pre- and post- 9 am. Yearly.
2c. Increased abundance of gliders	Utilisation by gliders for foraging will increase due to greater numbers of larger leaves, higher availability of flowers and other foraging resources.	The average home range of a Squirrel Glider is 1.5-6 ha (Soanes and van der Ree 2016). Glider species forage on leaves, plant exudates and invertebrates, and may also utilise ground resources (Bennett *et al*. 1991). Abundance of gliders has been associated with canopy height and cover, and density of mature and hollow-bearing trees (Bennett *et al*. 1991; Smith and Murray 2003).	Number of trees with glider notches	All trees in 9 ha plot. Yearly.
2d. Increased abundance of predators, in particular foxes, in the short term	Reducing stem density may make the forest more permeable to predators. However, this effect may be	There is little available evidence in the published literature to inform this hypothesis. A number of researchers have suggested that roading and disturbance in commercial forests have	Track or scat evidence (fox)	60 1m^2 plots. Yearly.

Hypothesis	Rationale for hypothesis	Relevant literature	Monitoring variable	Survey effort
	largely negated by increased cover of coarse woody debris.	increased predation on ground dwelling or nesting fauna (Smith *et al*. 1992; Claridge *et al*. 1991; both cited in Recher 1996). Scat counts can be indicative of relative abundance (Mitchell and Balogh 2007). Although the home range of foxes can be hundreds of hectares, we hypothesise that foxes will preferentially avoid densely treed areas.		
3a. Increased diversity and cover of exotic plant species in understorey in the short term, decreased in the long term	In the short term, the diversity and cover of exotic plant species may increase, as a result of increased availability of resources and thinning treatment disturbance. In the long term, native plant species will survive flood events and benefit from reduced competition to the detriment of exotic species.	Thinning trials in Brigalow vegetation did not result in invasion of exotic grasses in regrowth (Dwyer *et al*. 2010). Thinning in *Eucalyptus sieberi* regrowth did not facilitate an increase in exotic plant species (Bauhus *et al*. 2001). In a wet sclerophyll forest plantation, growth of both native and exotic species was stimulated by thinning (Cummings and Reid 2008).	Cover abundance of all exotic plant species	Three 0.04 ha plots. Yearly.
			Abundance of all exotic plant species	60 1m^2 plots. Yearly.
3b. Increased diversity and abundance of native plant species	Cover and abundance of native plant species will increase, and the diversity of species per unit area may also increase, due to increased availability of water (and other) resources. The process model workshop highlighted uncertainty in the response of native understorey plant species.	Richness of native plants is strongly negatively associated with canopy coverage in xeric RRG forests (Mac Nally *et al*. 2011). Researchers have noted variation in understorey responses to thinning amongst vegetation types (Bauhaus *et al*. 2001; Brown *et al*. 2010). Thinning increased: cover for tussock grasses and forbs in Box-Ironbark communities (Pigott *et al*. 2009); species richness in wet sclerophyll forest plantation (Cummings and Reid 2008); woody species and grass cover in Brigalow (Dwyer *et al*. 2010). Bauhus *et al*. (2001) found no significant changes in understorey composition or cover following thinning. Brown *et al*. (2010) note that changes may be smaller or slower in drier, more open forests than denser forest types.	Cover abundance of all native plant species (nearest 5%)	Three 0.04 ha plots. Yearly.
			Abundance of all native plant species	60 1m^2 plots. Yearly.

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