Using phenology of eucalypts to determine environmental watering regimes for the River Murray floodplain, South Australia

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Abstract

Trees on the River Murray floodplain in South Australia, particularly river red gum and black box (Myrtaceae: *Eucalyptus camaldulensis, E. largiflorens*), are increasingly water-stressed as the period since effective overbank flows extends to six years. As a result of declining health and dry conditions, recruitment rates in these species are insufficient to maintain populations. This study examined phenological cycles to determine the potential for timing environmental flows to promote recruitment. Results indicate a relatively consistent pattern in river red gums, which would benefit from watering in summer (December-February) to reinforce bud set, flowering and germination during peak seed rain from aerial seed banks. Present environmental flow programs may not provide water to black box on elevated areas of the floodplain, but this species would benefit from watering to reinforce bud set and flowering either in summer (December-February) or winter (May-July), depending on the phenological cycle of the trees to be watered. The possibility of watering to support seedlings in autumn, following above-average rainfall in the previous spring, warrants more study.

Keywords

Murray-Darling Basin, floodplain, eucalypt, river red gum, phenology, seed bank, seedling, water regime

Introduction

Flow patterns in the Lower River Murray (below the Murray-Darling confluence) have been altered by regulation by dams, weirs and diversions (Walker, 2006; Walker *et al.*, 1995). The effects have been to eliminate small floods (up to 1 in 7 y frequency; 25-40,000 MLd^{-1}) and to reduce the frequency and duration of medium floods (up to 1 in 20 y; 40-60,000 MLd^{-1}). As a result, the floodplain generally is drier (Roberts, 2003; Walker & Thoms, 1993). At Chowilla (17,770 ha, near Renmark, South Australia), natural flood frequencies of 1 in 2 y have been reduced to 1 in 4-5 y (Sharley & Huggan, 1995).

In the Lower Murray region, flooding is the primary source of water for eucalypts, recharging shallow aquifers and maintaining soil moisture (Jolly *et al.*, 1992), supplemented by local rainfall. The last effective overbank flows in this region were in 1996, with a small flood in 2000, and river red gum and black box trees (Myrtaceae: *Eucalyptus camaldulensis*, *E. largiflorens*) on the floodplain are severely affected; indeed, 95% of river red gums are dead or dying of water stress (MDBC, 2003). River red gums are most vulnerable as they favour areas where flood frequencies are 1 in 2 y (Roberts & Marston, 2000). Black box trees occur at higher elevations and are more drought- and salt-tolerant, but they too show signs of water stress (George, 2004; George *et al.*, 2005; MDBC, 2003). Seed volumes in stressed trees are significantly reduced (Jensen *et al.*, 2007) and recruitment rates in both species are insufficient to maintain current populations with higher adult mortality (George *et al.*, 2005).

In both species, the phenology of flowering and seed fall varies geographically. River red gums flower from September to February (George, 2004; Roberts & Marston, 2000) along the Murray, but in December and January elsewhere (Boland *et al.*, 1984; Paton *et al.*, 2004). Seed fall peaks in autumn and spring in the Lower Murray (George, 2004), in winter in the nearby Mount Lofty Ranges (Pudney, 1998), and in spring in the Barmah Forest, Victoria (Dexter, 1970). Black box trees flower from August to January in the Lower Murray (George, 2004), and from May to October in most of the Murray-Darling Basin (Roberts & Marston, 2000). Seed fall is from February to April (Boland *et al.*, 1984; George, 2004).

Action is needed to restore tree health and promote recruitment (the accrual of mature, potentially reproductive individuals) to these populations. Environmental flow programs are underway, but they are not well-supported by field studies. This paper draws from a PhD research program designed to discover ways to optimise the application of environmental flows to benefit the floodplain vegetation, especially eucalypts. It is a preliminary account; details will be published elsewhere (e.g. Jensen *et al.*, 2007).

Methods

Observations were recorded at seven sites in South Australia, between Morgan and the New South Wales border. These were Brenda Park, near Morgan, Banrock Station, near Barmera, and Monoman Island, Pipeclay Lagoon, Pilby Junction, Twin Creeks and Werta Wert on the Chowilla floodplain near Renmark. All sites were linked to controlled watering events, and those at Chowilla are part of *The Living Murray Program* developed by the Murray-Darling Basin Commission.

Monitoring from October 2004 to December 2006 covered a dry season (total rainfall 190 mm, 2004), a wet season (301 mm, 2005) and a dry season (119.4 mm, 2006) (Bureau of Meteorology data for Renmark: average 260 mm). Phenological data were recorded monthly for marked branches on nine river red gums and nine black box trees across the seven sites, to complement data from 12 seed traps at each location. A rank scale (0-4) was used to indicate the relative volumes of buds, flowers, immature fruit, mature fruit with closed valves and fresh leaves. Scores were: 0 = absent, 1= low volume (<25%), 2= medium volume (25-50%), 3=high volume (50-75%) and 4=very high volume (>75%). These data were plotted to reveal seasonal and inter-annual patterns. Other variables such as local rainfall, soil moisture and insect herbivory were monitored as part of the larger study; these will be included in future analyses of a more complete data set.

Results

River red gum bud crops followed an annual cycle, maintaining numbers to May-July and declining toward December or January as buds were shed (Figure 1). Buds were set in January-February, and surviving mature buds were held on the tree until flowering in November. Flowering peaked in December, although most individual trees flowered at two-year intervals. There was a substantially larger crop in 2006 than in 2005. Immature fruits occurred from October 2004 until April 2006, then were not recorded for 7 months (presumably these were aborted due to dry conditions). A new crop formed in December 2006. Mature fruits persisted throughout the sampling period and increased in volume in 2006, when immature fruit from 2005 matured. Fresh leaf growth peaked in December and continued through autumn, but with progressively smaller volumes from 2004 to 2006.

In overview, individual river red gums peaked in bud production in different years (for example, five trees produced higher bud crops in 2005, none in 2005 and four in 2006). The flowering patterns showed that trees either peaked in December 2004 and December 2006, or in December 2005. At Twin Creeks there was an additional low-intensity winter flowering event in June 2006, possibly due to aseasonal watering in May-July 2005 and again in March-April 2006 (natural flow peaks normally occur in October-December). Abundances of closed mature fruit were higher on six trees in 2006 and on two trees in 2005 (some trees had equivalent numbers of fruit in both years and so were not counted as having a single peak).

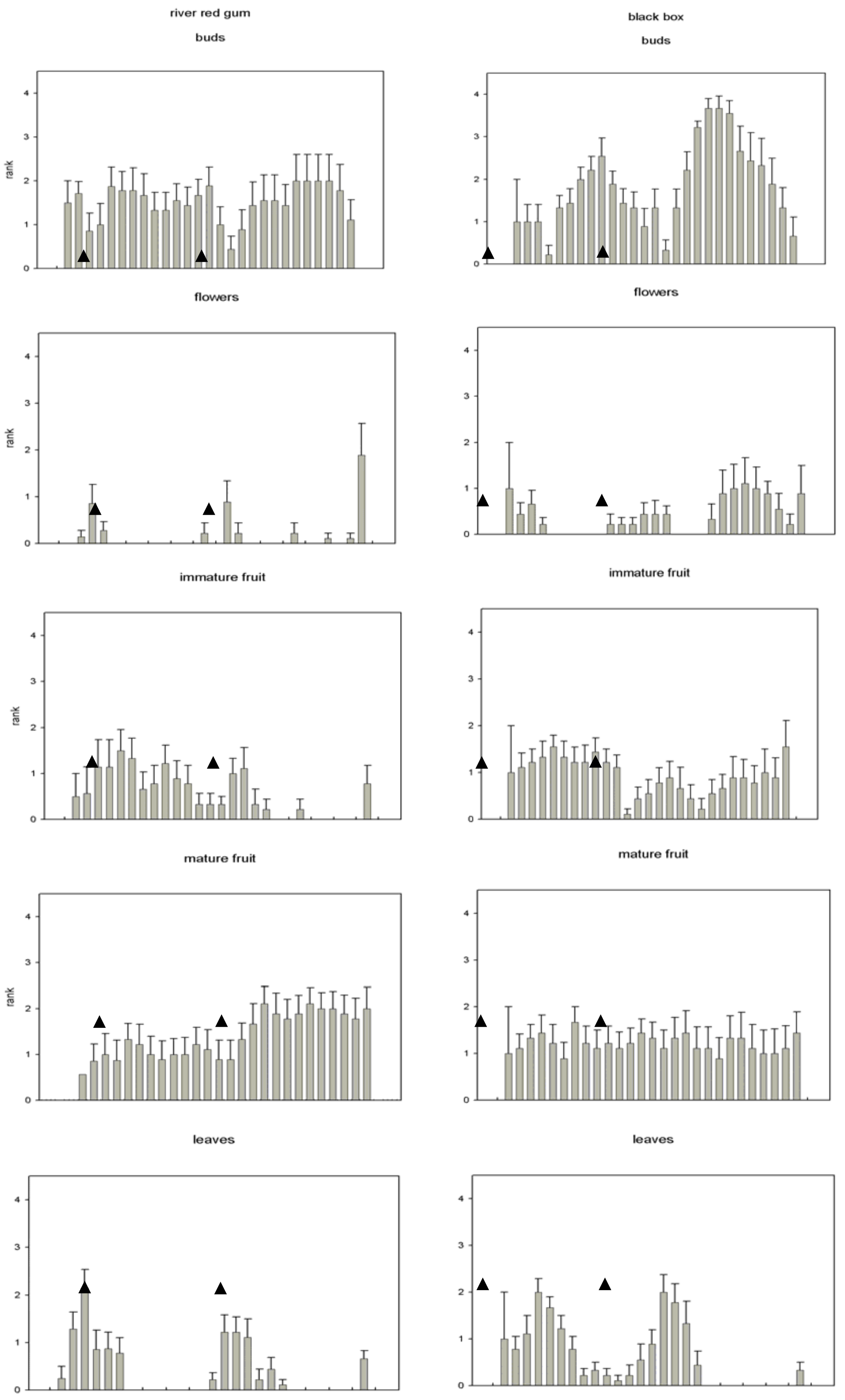

Figure 1. Phenology of nine river red gum (left) and nine black box trees (right) during October 2004 to December 2006 (Jan 2005, Jan 2006 indicated by arrows), showing relative volumes of production (average rank 0-4) for buds, flowers, immature fruit, closed mature fruit and fresh leaves.

Black box bud crops also showed an annual cycle, maintaining bud numbers until May-June (Figure 1). Very small bud crops were produced in January 2005 and December 2005. As with river red gums, there was a larger bud crop in 2006 than in 2005. Buds were set in January-February, and mature buds were held on the tree until flowering. Flowering occurred in October 2004-January 2005, July 2005-December 2005 and April 2006-December 2006. The only months when flowering was not recorded were February and March. Winter flowering occurred mainly at Chowilla sites (Monoman Island, Pilby Junction), while Banrock Station trees flowered mainly in summer. Immature fruit occurred throughout the monitoring period, but abundances were low in September 2005 and April 2006, and generally lower in 2006 than in 2005. Numbers of immature fruit increased again in December 2006. Mature fruits with closed valves persisted throughout the entire period. Fresh leaf growth peaked in summer and autumn, but continued throughout 2005 to March 2006. No new leaves were recorded from April 2006 to November 2006, and only a small volume in December 2006.

In general, the abundances of buds on individual black box trees peaked in different years (for example, one tree peaked in 2004, none in 2005 and eight in 2006). Numbers of flowers produced were highest for three trees in 2004, no trees in 2005 and three in 2006. Numbers of closed mature fruit were highest for four trees in 2004, one in 2005 and two in 2006.

Table 1 compares the phenology of river red gums and black box trees at the study sites in 2004-2006. These observations show that the summer months (Dec-Feb) as more critical for production in river red gum, with a short flowering season, while black box trees have more protracted stages, but also with peak volumes in summer. Both species retain bud crops (before flowering) and mature closed fruit (before shedding seed) in their canopies for extended periods, although the crop may be shed in response to poor conditions post-bud initiation and pre-flowering (Figure 1).

Table 1. Comparative phenology of trees at six sites on the Lower Murray, 2004-2006 (see also Jensen *et al.*, 2007)

	River red gum	Black box
Flowering	Mainly Dec. Most (78%) with biennial cycle. Minority with annual cycle and higher production in alternate years.	All months except Feb, Mar. Most with annual cycle and similar production in each year. Minority with biennial cycle.
Leaf production	Mainly in summer (Nov-Jan). Lower volume produced in dry conditions and some trees (45%) ceased production.	Year-round, peaking in summer (Nov-Feb). Volumes lower, and most trees (55%) ceased production in dry conditions.
Seed production	Peak release Dec-Feb Max. monthly peak 52,685 seeds m^{-2}	Peak release Oct-Mar Max. monthly peak 7,445 seed m^{-2}
Bud crops	Surviving mature buds retained for up to 12 months before flowering. Similar volumes in wet and dry years.	Surviving mature buds retained for up to 12 months before flowering. Larger volume (170%) after wet season.
Mature fruit	Retained on trees (closed valves) for up to 24 months before shedding seed. Increased volume in 2006 (173%).	Retained on trees (closed valves) for up to 24 months before shedding seed. Similar volumes in 2005, 2006.
Immature fruit	Varied annual cycle: longer in 2004 (Dec-Sep), shorter in 2005 (Dec-Jan). Only 30% of trees producing in Dec 2006	Annual cycle peak in Jan-Feb, declining to Sep.

Discussion

It appears that in both species the flower crop is determined by conditions occurring 12 months prior, and not by conditions in the current season. A similar time lag was apparent for the mature fruit crop, which peaked in 2006, 12 months after a wet season of 2005. Flowering cycles in individual trees may operate alternately, so that within a stand there are always likely to be some trees flowering in a given year. Trees at Pipeclay Lagoon, Werta Wert and Twin Creeks at Chowilla flowered in the same year as those at Morgan (2005), while trees at Banrock Station and Pilby Junction (Chowilla) flowered in alternate years (2004, 2006).

River red gum and black box exhibit *serotiny* (Lamont & Enright, 2000). That is, they retain most of their seeds in the canopy and release them as light, continuous seed rain, or they may produce heavier falls after seasonal rain. Seed release on the Lower Murray peaks in summer for river red gum (Dec-Feb) and over a longer period for black box (Oct-Mar) (Jensen *et al.*, 2007). Seeds are held in the aerial seed bank for at least two years.

The annual rainfall threshold for recruitment of eucalypts on the Lower Murray floodplain is about 300 mm, and the minimum flood required is 40,000 ML d^{-1} (George *et al.*, 2005). There have been no natural floods since 2000. In 2004, rainfall was below average (190 mm); in 2005 it was above average (301 mm), and in 2006 it was again below average (119 mm). River red gum seedlings emerged in response to rainfall in 2005 (Jensen *et al.*, 2007). There appears to have been a time-lag from rain in 2005 until production in 2006 of flowers and mature fruit in river red gum and buds and flowers in black box. In 2006, drought caused abortion of immature fruit in river red gum and suppressed leaf growth in black box.

Jensen *et al.*, (2007) suggested that, given the trend of drier conditions on the floodplain, timing environmental flows to augment rainfall or flooding could increase rates of seedling survival, hence recruitment. Small, targeted watering events could be timed to maintain soil moisture levels to sustain particular phenological phases. These data, and the phenological observations described here, suggest that a plan for managed watering events could be:

- at flowering/bud set (Dec-Feb, for both species),
- at peak seed rain (Dec-Feb for river red gum; May-Jul and Nov-Jan for black box),
- 1-2 months after spring rain, to support seedlings (Oct-Dec),
- 1-2 months after small floods (>40,000 ML d^{-1}), to support seedlings (Dec-Feb), and
- 12 months after above-average rain to maintain bud crops and aerial seed banks (Mar-Jun), and in subsequent years if conditions are dry.

These suggestions should be tested experimentally, but with regard for possible negative impacts. Watering of stressed river red gums at Monoman Island (Chowilla) in March 2004 produced aseasonal fresh leaves, but several trees died, apparently stressed beyond recovery (Lichtenthaler, 1996). Another hazard is top-flooding and drowning of new seedlings by later watering events.

In both eucalypts, seedling survival appears to limit recruitment and depends on soil moisture, hence rainfall and flooding (Jensen *et al.*, 2007). Jensen (2002) suggested that environmental flows should be timed to duplicate flow peaks (post-regulation in early-mid summer) to stimulate germination, but the available volumes of water and the logistics of delivering water to floodplain sites would limit their effectiveness. The guidelines suggested here may prove useful as an alternative approach for timing of environmental flows designed to promote increased seed production, by watering to promote flowering and bud set, by matching peak soil moisture with peak seed rain to promote germination, and by maintaining soil moisture levels to increase survival of seedlings germinated by natural watering.

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