FUNCTIONING FLOODPLAINS OR TREE MUSEUMS?

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Abstract

Under current agreements, State and Federal governments plan to deliver 'environmental flows' to ecologically significant sites along the River Murray, to restore the health of wetland and woodland communities. This is a topical solution that relies on individual trees acting as indicators of floodplain condition. Investigations of regeneration in the two dominant tree species, river red gum (*Eucalyptus camaldulensis* Dehnh.) and black box (*Eucalyptus largiflorens* F. Muell.), show that simply improving tree health may not necessarily improve holistic floodplain function. Poor health reduces the reproductive capacity of trees (flower, seed capsules and seeds) limiting the availability of seed for germination and recruitment. Numbers of seedlings and saplings are currently insufficient to maintain woodlands in South Australia at their current densities suggesting that as trees die they will not be replaced. Regeneration relies on overbank flows from the river, and different flow patterns of flows are required by immature and mature trees. Environmental flows should therefore be tailored to different age classes rather than simply to maintain survival of mature adult trees. For floodplain woodlands, the greater problem lies with recruitment or reproduction at a population scale.

Keywords

Environmental flows, eucalypts, floodplain, regeneration

INTRODUCTION

The Murray is the principal river in the 1.073 M km^2 Murray-Darling Basin in south-eastern Australia, and flows 2560 km westward from the Snowy Mountains to the sea near Goolwa, South Australia (e.g. Walker, 1992). As most of the Basin is semi-arid, rainfall and runoff vary widely in space and time. Historically, this has encouraged major diversions of water and intensive flow regulation through dams and weirs. The river system now provides water for 16 cities and 41% of Australia's gross agricultural production, mainly through irrigated crops and pastures (Crabb, 1997). Despite annual diversions being "capped" at levels that prevailed in 1993-1994, present levels of diversion arguably are not sustainable. There are widespread declines in native flora and fauna, and associated problems of salinisation and vegetation clearance (MPPL, 1990).

The area of native vegetation in the Murray-Darling Basin has decreased by 30% over the last 200 years, and there is a continuing decline in the condition or 'health' of surviving trees, especially riparian woodlands of river red gum and yellow, grey and black box (MPPL, 1990; Webb and Nichols, 1997). Recently, the Murray-Darling Basin Commission (2005) reported a 20-60% increase in the number of stressed trees in Murray floodplain woodlands. This represents an increase in health decline from 51-75% over a 2-year period (Murray-Darling Basin Commission, 2003, 2005).

In 2001, a panel of scientists appointed by the Murray-Darling Basin Commission declared that an annual "environmental" allocation of 1500 GL was needed to arrest the declines of flora and fauna, and to provide a moderate chance of recovery (Jones *et al.*, 2002). In response, the Murray-Darling Basin Ministerial Council established *The Living Murray* (TLM) initiative. A "First Step Decision", administered by the Murray-Darling Basin Commission, was to recover up to 500 GL for six areas along the River Murray, identified as "Significant Ecological Assets" (SEAs) (Murray-Darling Basin Commission, 2004). TLM coordinates the activities of state jurisdictions and their regional agencies, and is concerned primarily with strategies for planning and deployment of "environmental flows".

One SEA in South Australia is the Chowilla floodplain, where the declining health of trees, characteristic of floodplain trees in South Australia, is apparent in the loss of canopy density, the prevalence of epicormic growth and infestation by mistletoes (Miller *et al.*, 2003; Murray-Darling Basin Commission, 2003). The condition of adult trees, however, is a superficial symptom, and sustained recovery will require water to maintain not only survival, but growth and reproduction (cf. Walker, 2002). Moreover, the recruitment and survival of individual trees need to be at a level commensurate with the mortality of adults, if the population is to be maintained. George *et al.* (2005) showed that in some areas of the Murray floodplain young trees are not surviving in numbers sufficient to replace older stands. The implication is that, as older trees die from natural causes, for lack of water or intolerance to salt, entire populations will regress.

The challenge for TLM therefore is to design and implement environmental flow programs that will promote the maintenance and regeneration (flowering, seed set, seed dispersal, germination, seedling survival, establishment) of floodplain trees at a level consistent with the maintenance of populations and communities. Within this context, the present paper explores the relationship between flow history and tree regeneration, and the relationship between tree health and reproductive potential, in the two dominant eucalypt species of the Murray floodplain in South Australia, namely river red gum (*Eucalyptus camaldulensis*) and black box (*E. largiflorens*).

METHODS

Study Area

Studies were conducted at Banrock Station, near Waikerie, on the Murray floodplain in South Australia (Figure 1), where the regional climate is semi-arid with a mean annual rainfall of 250 mm. No significant tributaries enter the river below the Darling confluence in Victoria, and the river is dominated by 10 weirs, six of them within South Australia (Walker and Thoms, 1993). The river now is a series of weir pools maintained at or near bankfull capacity (Maheshwari *et al.*, 1995; Walker, 2000; Walker, 2005), and the banks are breached only by large floods (Close, 1990). Weir operations have contributed to the altered flows in the river, and to changes in channel and floodplain conditions, including erosion and deposition, salinisation of soil and water, and degradation of wetlands (Walker, 2005)

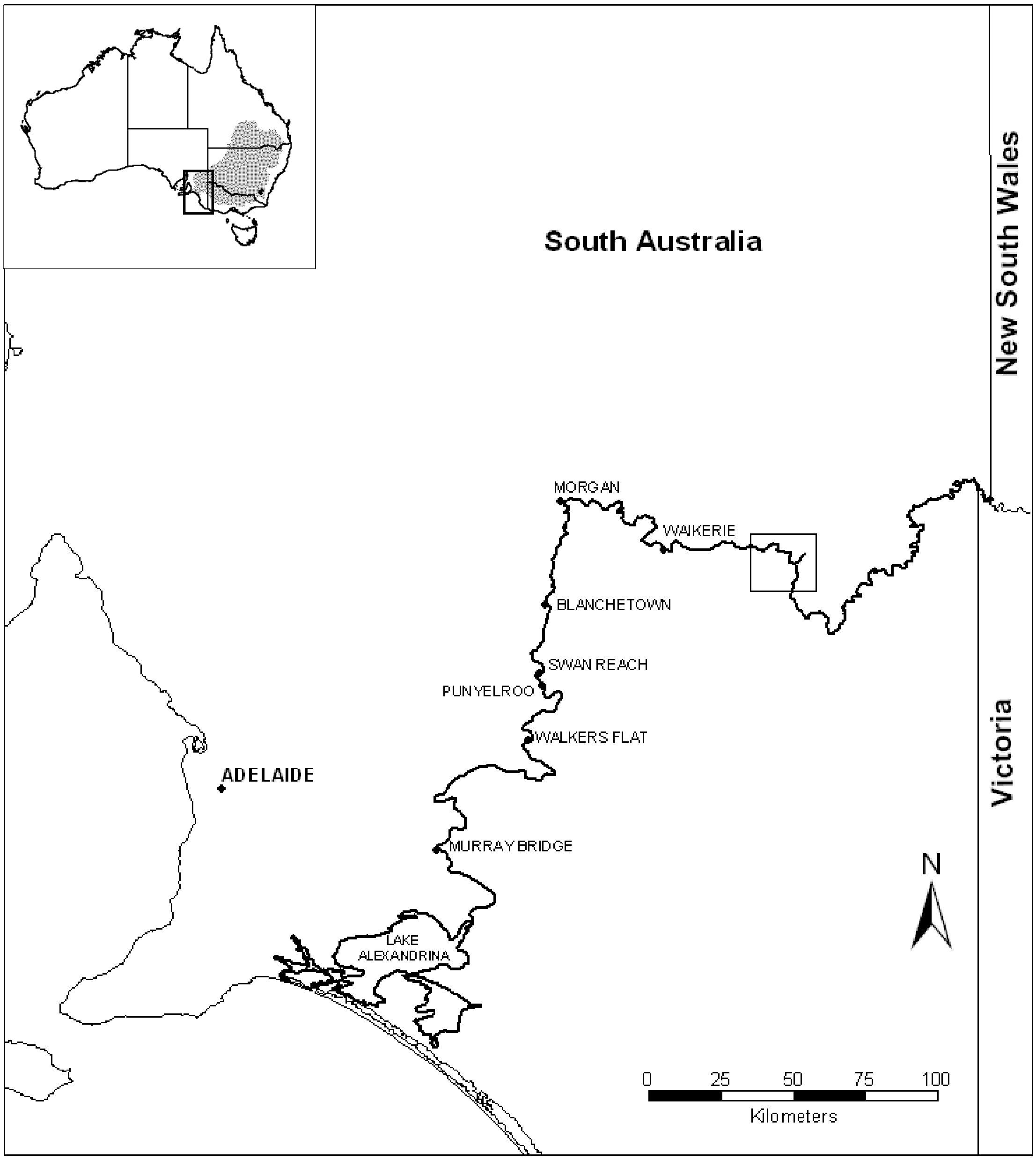

Figure 1. The River Murray in South Australia. Tree surveys and monitoring were conducted at Banrock Station, located within the delineated square.

Flow Requirements

The spatial distribution of floodplain trees at Banrock Station was compared with the regional flow history (the recent history of flow changes: Puckridge *et al.*, 1998). Red gum and black box trees were surveyed in 127 circular plots. Trees were classified by growth stage (seedling, sapling, pole, mature), and their spatial distributions were mapped using GIS software (ArcMap 8.1). Growth stages corresponded to predicted growth forms based on tree height (greater or less than 1.3 metres) and canopy structure, including size and shape of the main stem and primary branches. Minimum flow magnitudes to inundate each growth stage were estimated using the River Murray Flood Inundation Model III (Overton, 2001). This model uses daily flow data collected at the South Australian border to map the spatial extent of flooding at defined magnitudes. The model calculates minimum flow magnitudes by comparing river stage height with derived floodplain elevation.

To further define the relationship between river flows and cambial growth, dendrochronological techniques were applied to two black box known to be germinated by floods in 1956, three red gum from 1956 and three red gum from 1978. Tree rings were counted and measured for each tree. Average ring widths were compared with historical river flows and total annual rainfall during the corresponding time periods.

Reproductive Potential

To determine the potential long-term implications of reduced tree health seed fall and bud development were monitored in ten vigorous, healthy and ten unhealthy, poor trees of each target species over two years. Seed production and viability were assessed monthly by germinating seeds collected from elevated seed traps. Seeds were germinated using the emergence technique, and ‘viable’ seeds were regarded as those germinating and those passing the squash test (Gunn, 2001). The proportion of viable seeds relative to non-viable seed under favourable germination conditions was then calculated. These data provide some indication of potential regenerative capacity based on seeds within tree canopies.

Floral buds and fruit capsules were monitored concurrently to determine the rate of development. At bud initiation, 50 buds were tagged within the canopy of each sample tree. The developing floral buds were measured monthly across the widest portion of the hypanthium, representing the rate of development prior to flowering. The measurements were intended to define the relative size that buds must reach before flowering is initiated. Bud measurement continued through flowering and fruit maturation. Post-flowering measurements represented the rate of fruit capsule development and seed maturation. Fruit capsules were measured until seed shed occurred or fruit capsules disappeared from the canopy.

RESULTS AND DISCUSSION

Flow history and tree distribution

Mature trees at Banrock Station were found to be more widespread than younger stages (pole, saplings and seedlings) (Figure 2). Seedlings were restricted to clumps along the margins of the floodplain and main river channel. Saplings were distributed along the border of the floodplain and in the less-frequently inundated areas. Pole trees were concentrated where water accumulates from river flows or run-off from surrounding cliff faces and irrigation areas. The greater dispersion of mature growth stages indicates an apparent shift in localized regeneration since regulation. Mature tree distribution reflects where river flow regimes sufficiently allowed trees to progress through germination, recruitment, establishment and reproductive maturity. As regulation has intensified river flow regimes have been altered so that the younger growth stages have fewer opportunities to progress through the regenerative stages. The result is the limited distribution and lower density of younger growth stages relative to mature trees.

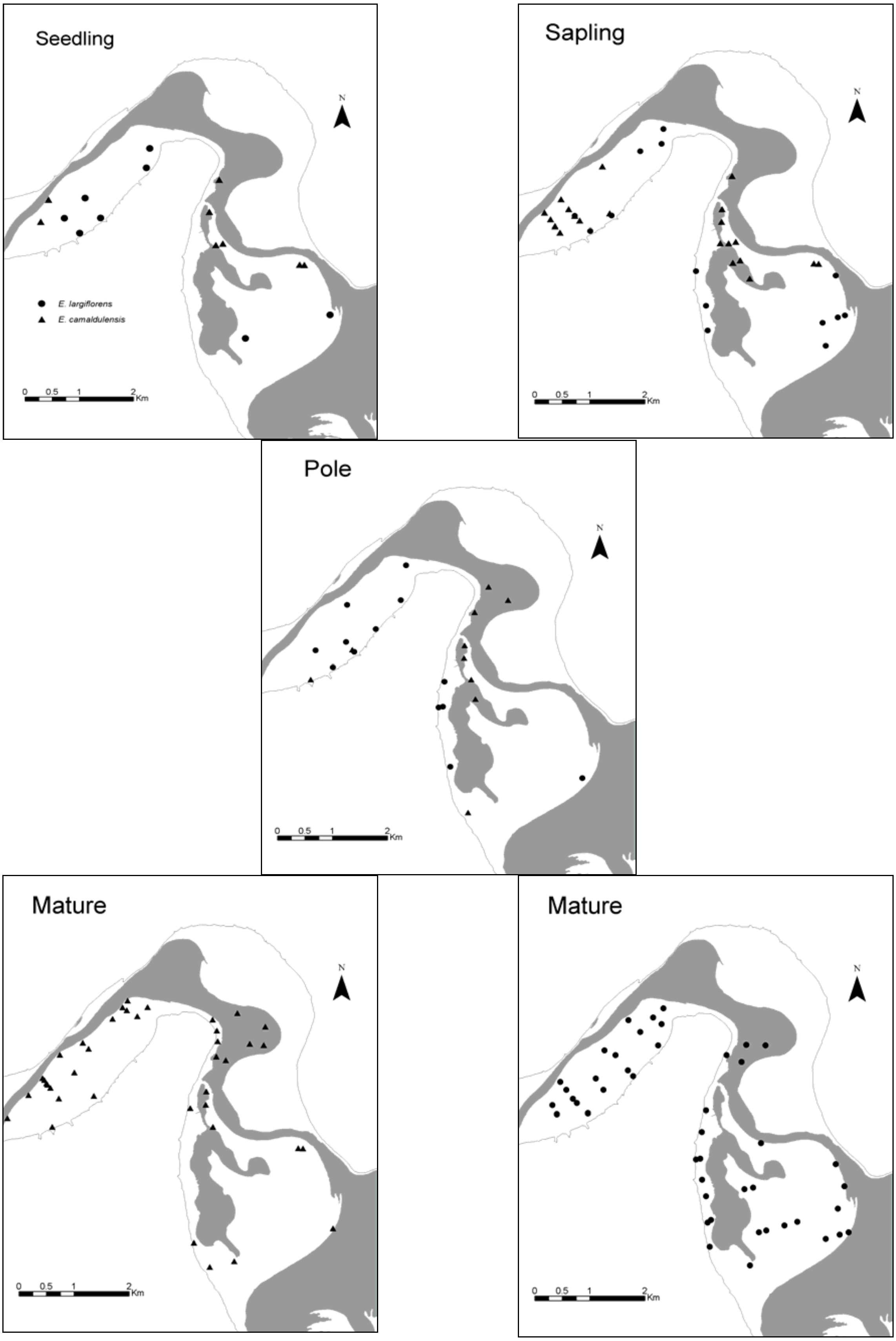

Figure 2. Growth stage distribution for (•) black box and (▲) red gum across Banrock Station. Note that maps for mature trees are divided by species, while early growth stage distributions are combined. Each dot marks the presence of the growth stage across the site.

A shift in localized regeneration is further illustrated by the range of flows, or flow history, experienced by each growth stage. The natural flow regimes of rivers, reconstructed from historical data, provide a template for conservation and management (Poff *et al.*, 1997; Walker, 2002). Community structure and other ecological features can reflect the local hydrological conditions resulting from flow variability evident by the spatial variation in fish, waterbird and riparian trees (Walker, 2002). Floods have cumulative effects both spatially and temporally, enabling organisms to augment recruitment, dispersal and establishment (Walker, 2002). Because the flow history for mature trees potentially spans 100 years, while that of seedlings may span only 10 years, the range of flows inadvertently shows the flows necessary to initiate germination and recruitment (Table 1). The wider range of flows for mature trees reflects germination prior to intense regulation, thus establishment under a more natural flow regime. Additionally, younger stages reflect recruitment and regeneration under regulated conditions. The minimal inundating flows between 63,000 and 70,000 ML day^{-1} in younger black box imply a reliance on moderate sized flows for extensive recruitment. Dexter (1978) determined a similar relationship, referencing six periods during which high rates of localized regeneration of red gum occurred. Each of these periods was during, or following, a year with flows at least 59,000 ML day^{-1} or greater.

Table 1. Range of flows required to inundate growth stages of black box and red gum at Banrock Station. Flows were derived using the Flood Inundation Model, which compares river flows and elevation to determine the minimum river flow required to inundate an area.

GROWTH STAGE	INUNDATING FLOWS (1000 ML DAY^{-1})
Black box seedlings	63 – 102
Black box saplings	63 – 102
Black box pole	70 – 102
Black box mature	38 – 102
Red gum seedlings	5 – 77
Red gum saplings	5 – 77
Red gum pole	5 – 70
Red gum mature	5 – 102

Tree rings

Evaluation of tree ring widths relative to flow history and rainfall illustrated a similar reliance on moderate sized flows. The 1956 trees provided the most comprehensive information. The younger 1978 trees had highly variable ring widths which likely reflect their younger age and smaller size. Younger, smaller sized trees will be able to access water more opportunistically from multiple sources therefore, their early growth rings are less likely to reflect a difference between rainfall and river flows.

Positive growth response was evident in both cohorts when moderate sized flows were coupled with average or above average annual rainfall. Figure 3 shows that the 1956 growth response, inferred from wide ring widths, was greatest when peak flows were between 40,000 and 80,000 ML day^{-1} and total rainfall was 250-300 mm. A positive growth response in red gum also resulted from higher rainfall (>300 mm) combined with lower peak flows (30,000 ML day^{-1}). The 1978 trees responded similarly to magnitudes of 40-60,000 ML day^{-1}.

However, cambial growth was suppressed by saturated conditions, occurring when flows exceeded 80,000 ML day^{-1} and rainfall was well above average. As indicated by the presence of narrow rings, both the 1956 red gum and black box showed greatly reduced ring widths during excessively wet years. For example, ring width is greatly reduced during 1973 – 1975, where flows exceeded 80,000 ML day^{-1} and total rainfall was greater than 300 mm. A similar response was found in the 1978 trees during high flows in 1993. This type of response suggests a relative threshold of 80,000 ML day^{-1} coupled with rainfall in excess of 350 mm for cambial expansion in floodplain trees. The importance of this point lies in the fact that different growth stages exhibited similar responses to excessive amounts of water, so there is little benefit to any growth stage from flows that inundate with exceedingly high flows or rainfall.

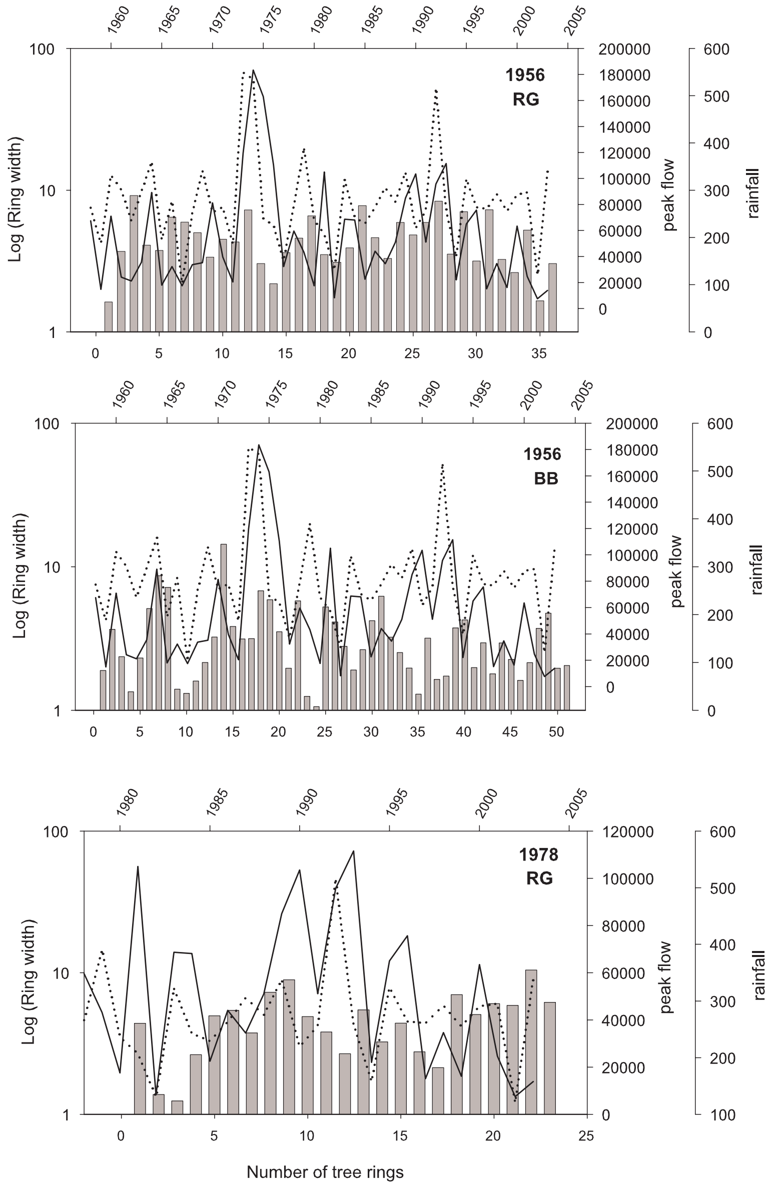

Figure 3. Ring patterns and associated rainfall and river flows in red gum (RG) and black box (BB) trees germinated in 1956 and 1978 near Swan Reach. (Bars = growth rings; dotted line = total annual rainfall in mm; solid line = river flow in ML day^{-1}). Note scales for each x-axis differ depending on the total number of tree rings counted.

Regeneration and health

Health survey

Survey trees were classified as ‘healthy’ or ‘poor’, based upon visual assessment of crown condition. As shown in Figure 4, even the smallest diameter classes were dominated by trees in poor condition. Only three of the red gum diameter classes and one of black box exhibited a greater number of healthy trees compared to poor. The different diameter classes represent the stages or steps involved in ensuring population maintenance from recruitment to reproductive maturity. If the poor trees die or fail to successfully reproduce, the proportion of trees available for continued population response to environmental flows is limited. Such limitations imply environmental flows would need to not only provide for survival but also improve health to a point that reproduction is actively occurring in order to prevent continued losses.

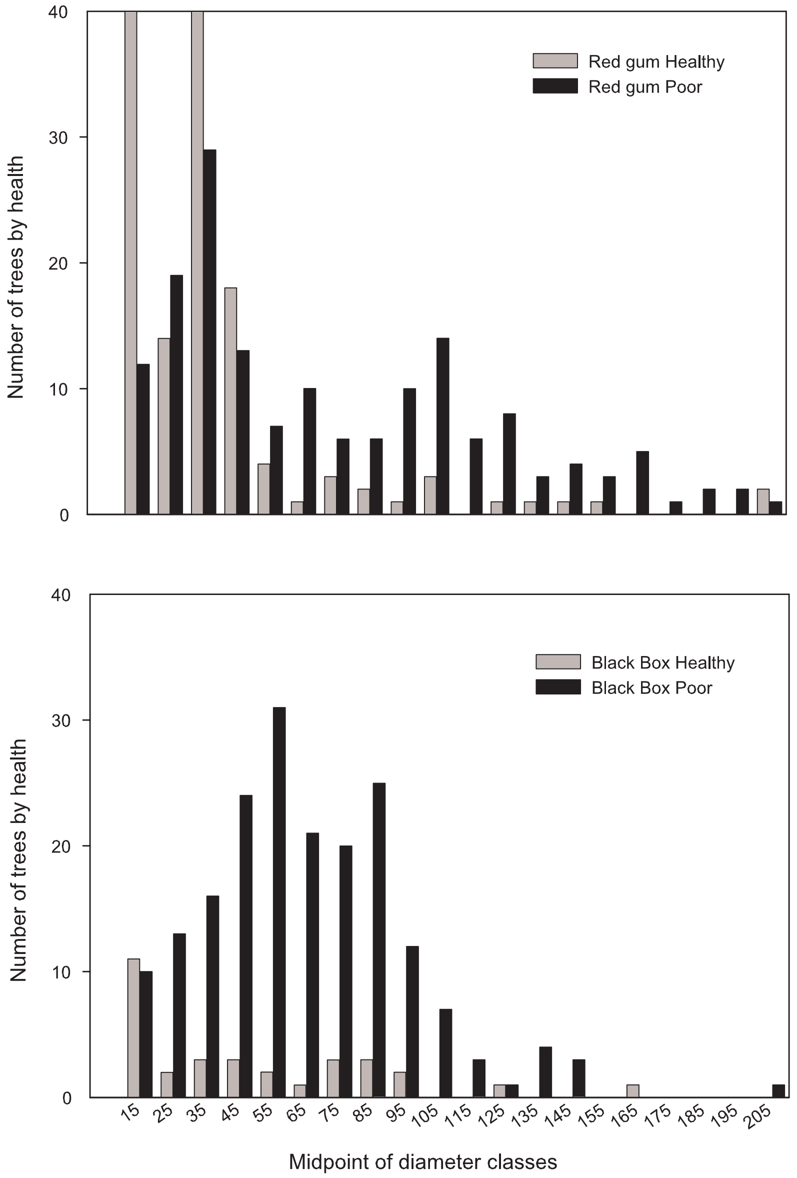

Figure 4. Density of red gum and black box trees at Banrock Station, based on diameter and health classification.

Seed production and viability

The quantity of seeds, as inferred by germination, is affected more by adult tree health than seed viability. The total seed fall for healthy and unhealthy trees was reduced (Figure 5). Healthy red gum trees are estimated to produce 600,000 seeds (Jacobs, 1955), yet six such trees at Banrock Station yielded only 28,000 seeds. The number of seeds captured could have been altered by any number of factors including seed predators, wind (dispersing seeds beyond the canopy boundaries), or in accordance with the study objectives, reproductive loss due to health decline. Regardless, seed capture was much less than what may be considered a 'fair yield' for these trees.

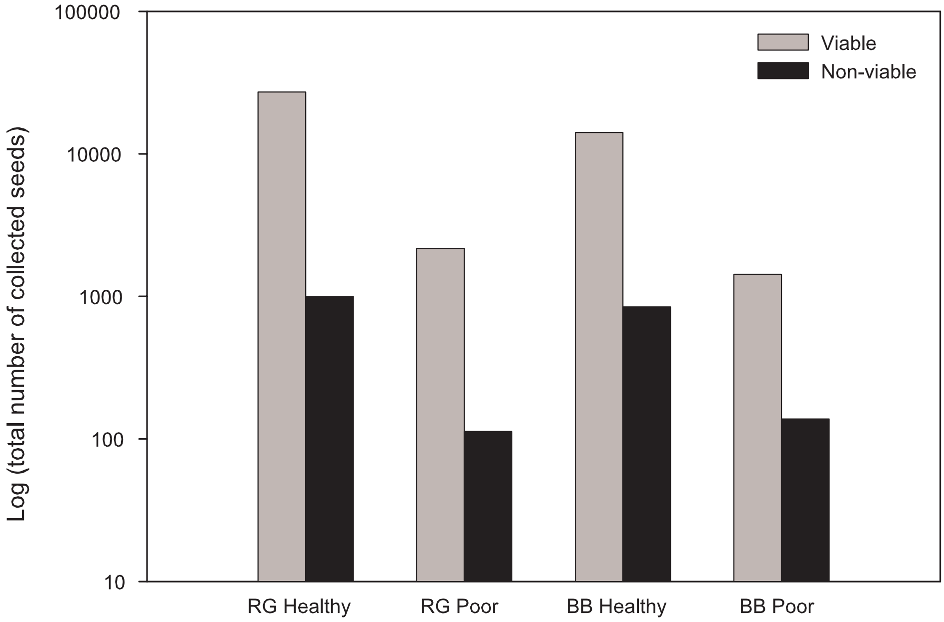

Figure 5. Seed viability relative to visual health for red gum (RG) and black box (BB).

The evident differences between health categories could be reflecting variation between individual trees rather than the effects of overall health; nested ANOVA was applied to examine this point. Despite significant differences between individual trees ($p < 0.001$), F ratios isolating the effects of health from individual trees indicated no significant impact on seed viability ($p = 0.33$, $F = 1.01$, df = 1, 22). However, overall health did contribute to the variance for seed production ($p = 0.0002$, $F = 19.04$, df = 1, 22). Thus, seed viability appears to be determined by the health of the individual trees rather than a more broadly applied mean visual health within species. Seed production appears to be impacted by the mean health of the species and individual tree health.

Bud development

Bud development appeared to be greatly reduced by health in both species. Not only were bud sizes stunted, the rate of development was much slower in poor health trees (Figure 6). Development is represented by the maximum size of buds and capsules. The maximum bud size prior to flowering was 4 mm for black box and 4-5 mm for red gum. After flowering, red gum capsules continued to increase in size to 6-7 mm, but black box capsules tended to remain at 4 mm. As with other factors, poor trees of both species deviated from these measures. Capsules from poor red gums reached 4 mm prior to flowering but did not increase substantially after flowering generally obtaining a maximum size of 5 mm. Capsules in poor black box trees did not reach 4 mm prior to flowering, as in healthy trees. Instead, these buds flowered at just over 2 mm and reached a maximum diameter of only 3 mm.

(a) (b)

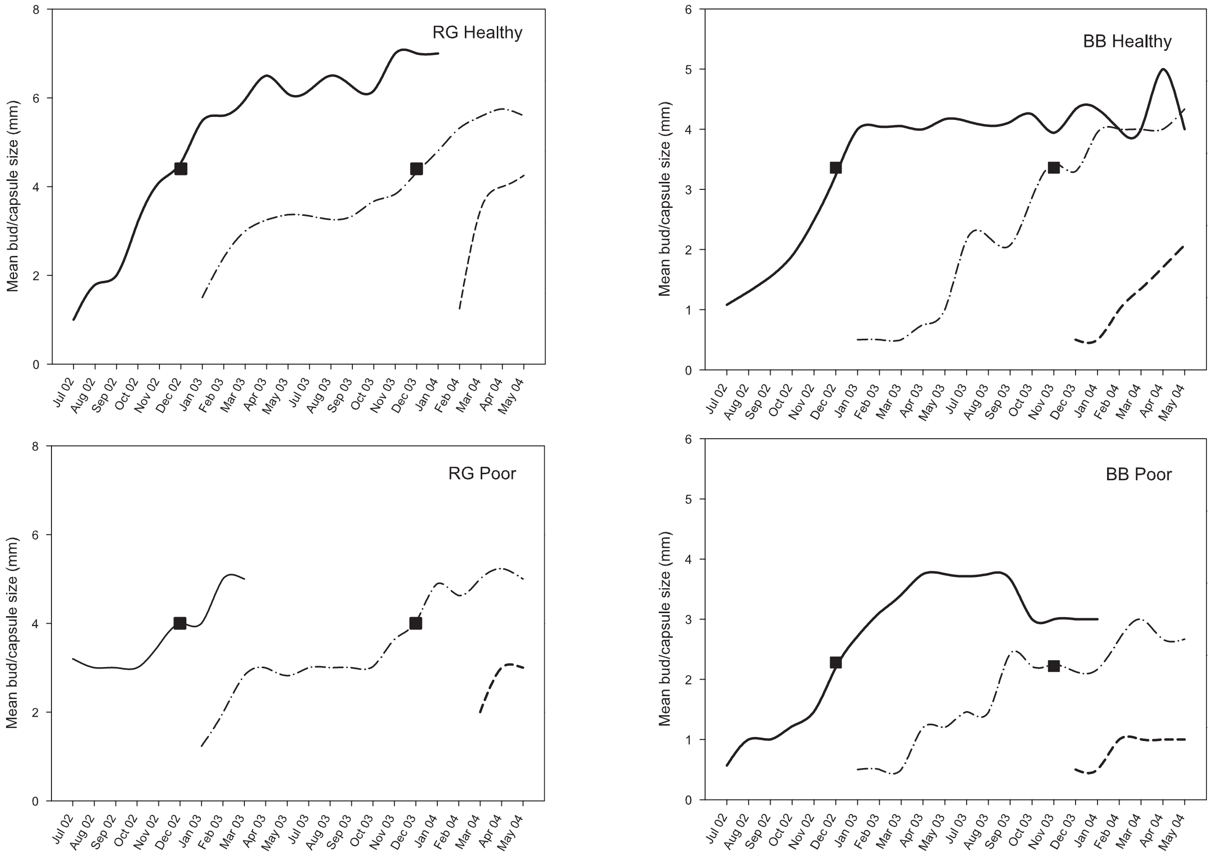

Figure 6. Three groups of developing buds from bud initiation to fruiting for red gum (a) and black box (b). Each line represents a single bud group with the timing of peak flowering indicated by a square. (RG = red gum; BB = black box).

A notable observation was the absence of multiple bud crops in the canopy of healthy red gums. Red gums are believed to store seed in the canopy (Jacobs, 1955), avoiding seed predation from insects and retaining seed viability independent from ground conditions. However, healthy red gums in this study generally carried only a single bud crop at a time. Single bud groups in healthy trees indicates that retention of multiple bud groups may be a response to stress rather than a typical seed conservation measure (Pryor, 1976; House, 1997; Pudney, 1998). The limited number of poor health trees showing bud initiation (Figure 7) and the relatively low proportions of canopy holding new buds illustrate potential problems related to health. Successful seed fall in poor trees that have failed to initiate buds during the entire study implies some other source of seed was available. Observations of the canopies showed a prevalence of over-mature capsules in poor trees. While over-mature capsules may hinder seed fall because of excessive woody growth (Cremer, 1965) they may be a means by which trees in poor health can sustain reproduction despite reduced physiological capacities.

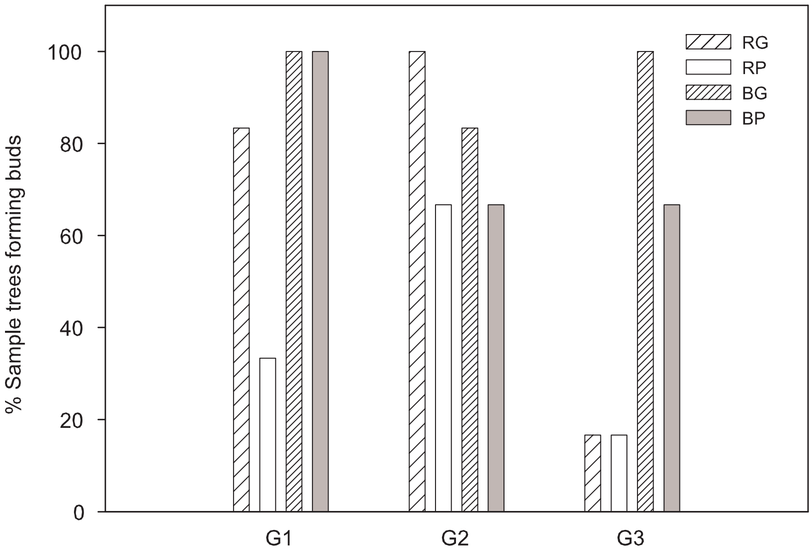

Figure 7. Percent of sample trees at Banrock Station contributing to the bud groups initiated during the study. G1, G2 and G3 correspond to the bud groups represented in Figure 6. Each species and health class was comprised of six trees (n = 6). (RG = healthy red gum; RP = unhealthy or poor red gum; BG = healthy black box; BP = unhealthy or poor black box)

CONCLUSIONS

The current state of health and limited distributions of floodplain trees reflect substantial changes to the Murray's flow regime, caused by regulation (Maheshwari et al., 1995). Trees are found in limited patches where moderate flows still inundate the floodplain, and the significance of these flows is shown also by tree growth-ring analysis. On the other hand, high magnitude flows, although less affected by regulation, have less benefit for cambial growth. Although environmental flows have relatively short-term effects (Bren, 1987; Richter *et al.*, 1996), many smaller floods during a given period could simulate the effects of a single large-scale flow event (cf. Robertson *et al.*, 2001). If this is so, environmental flows delivered by TLM could be of most benefit if managed as multiple moderate flows rather than single large events.

This study directly examined the association between health and the reproductive potential of trees, given that outwardly visible stresses reflect physiological status and capacity to contribute to the next generation. The results show that the early stages of regeneration, including seed production, budding and fruit formation, are all substantially altered by reduced parent health. The early stages of the regeneration cycle examined in this study suggest that eucalypts in poor health may be approaching a condition that (Lichtenthaler, 1996) calls the 'Stage of Exhaustion', where there is permanent, irreparable damage and death is imminent. Reduced reproductive effort has cumulative effects, as seed production declines; there are fewer early growth stages and less recruitment to the mature adult population. Flow allocations through TLM should aim not only to improve health but to benefit multiple growth stages and promote the establishment of early growth stages.

The recruitment of individuals is often wrongly equated with maintenance of populations, but regeneration is only successful when the progeny become mature and reproductive. The security of populations depends upon the frequency of recruitment and the number of recruits (Walker, 2002). If regeneration processes are impeded, the population will become fragmented and the habitat provided by trees will decline, with repercussions for many other floodplain biota. The plan to provide environmental flows only to SEAs may encourage the decline of floodplain communities between SEAs. As seed viability in red gum and black box trees is relatively short (7-10 days), and dispersal is correspondingly limited, the opportunities for isolated tree populations to supply seed will be few. Given the distribution and parlous condition of many floodplain trees, The Living Murray initiative should be directed at promoting recruitment and ensuring active growth and maturation, so that regeneration is sufficient to maintain long-term floodplain tree populations across wide areas.

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