

Impact of fire on bellyache bush (*Jatropha gossypifolia*) plant mortality and seedling recruitment

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Abstract.

A 2-yr trial investigated the efficacy of fire as a control technique for bellyache bush (*Jatropha gossypifolia*) in riparian habitats. Spring burns were applied in successive years (September 1999 and October 2000), and their impact on juvenile, mature and old bellyache bush plants was determined. Post-fire seedling recruitment was monitored for 21 months after the initial burn. The first fire significantly ($P < 0.05$) reduced the original bellyache bush plant density by 76% (from 10 750 plants/ha to 2580 plants/ha). A second fire a year later extended the kill rate (8 months after the second burn) to 92%, with a residual plant population of 860 plants/ha. Monitoring for a longer period would confirm the results obtained with the second burn. The relative sensitivity to fire was juvenile > mature > old. In contrast, seedling emergence was significantly ($P < 0.05$) increased after burning. Emergence in burnt plots over the wet season following the first fire was 2.7-fold that in unburnt controls. Even with high mortality during the subsequent periods, seedling density in burnt plots at the end of the study averaged 368 000 per ha compared with 40 000 per ha in the unburnt controls. It is expected that the residual population of bellyache bush would produce enough seed to soon reinfest the area. These results stress that fire should be one of a number of tools, which may be used for control of bellyache bush. They also highlight the need for development of integrated control strategies that not only treat the primary infestations but also the many seedlings that emerge from the residual soil seedbank.

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Introduction

The exotic weed bellyache bush (*Jatropha gossypifolia*) predominantly infests riparian habitats (Bebawi and Campbell 2002a) but can spread into open pastures and rocky areas in regions where annual rainfall ranges between 200–1500 mm (Bebawi *et al.* 2001). The worst infestations in Queensland are currently found along the banks of the Burdekin River and its tributaries (Csurhes 1999). Dense stands are known to prevent the growth of pasture grasses, obscure fence lines, interfere with mustering (Miller and Pitt 1990), compete with and displace native vegetation and reduce profitability of cattle enterprises (Miller 1982; Csurhes 1999). Furthermore, most parts of the plant, including seeds, are toxic to livestock (Parsons and Cuthbertson 2001).

Control activities undertaken on bellyache bush to date have mostly been on an *ad hoc* basis and generally confined to the use of chemicals (Csurhes 1999). Herbicides are expensive, as well as logistically difficult and costly to apply in remote locations (Carter and Signor 2000; Schroder and Howard 2000). Observations following chemical control also suggest that large-scale recruitment will occur over the ensuing wet season (J.S. Vitelli, personal communication).

Fire has proven an effective control option for several exotic woody species invading Queensland's rangelands, particularly rubber vine (*Cryptostegia grandiflora*) (Grice 1997; Bebawi and Campbell 2000; Bebawi *et al.* 2000) and mesquite (*Prosopis pallida*) (Campbell and Setter 1998). However, some species such as chinee apple (*Ziziphus mauritiana*) are highly resistant and can withstand burning from an early age (Grice 1997). To date, the susceptibility of bellyache bush to fire has not been quantified but warrants investigation. If effective, fire will provide an additional control technique which is relatively cheap in comparison with the alternatives (Hodgkinson and Beeston 1995) and which can be readily applied over large areas.

This paper reports the results of a study designed to investigate the effects of fire on mortality of bellyache bush plants growing in a riparian habitat. Post-fire recruitment was also monitored.

Materials and methods

Site description

The experiments reported in this paper form one component of a larger study investigating the impacts of fire on bellyache bush in a riparian site (1 km²) at 'Shilo', a cattle property (20°05'S, 146°10'E), 15 km NNW of Charters Towers. The term 'riparian' is used in this study to describe creek habitats (riverine habitats), which undergo ephemeral flooding during the rainy season.

Total annual rainfall during 1999 and 2000 was 807 mm and 1248 mm, respectively, with 90% falling from November–March (Figure 1). Average monthly maximum temperature in summer is 31°C and average monthly minimum temperature in winter is 10°C. Prior to this investigation, the site had not been burnt for 12 years (Bud Abbott, Landholder of 'Shilo', personal communication).

The site has herbaceous vegetation dominated by buffel grass (*Cenchrus ciliaris*), Mossman River grass (*C. echinatus*), couch (*Cynodon dactylon*), parthenium weed (*Parthenium hysterophorus*), feathertop rhodes grass (*Chloris virgata*) and liverseed grass (*Urochloa panicoides*). The shrub stratum was dominated by bellyache bush, castor oil plant (*Ricinus communis*), lantana (*Lantana camara*), rubber vine (*Cryptostegia grandiflora*), chinee apple (*Ziziphus mauritiana*) and mimosa bush (*Acacia farnesiana*), while a mixture of bloodwood (*Eucalyptus erythrophloia*), narrow-leaved ironbark (*E. crebra*), river tea tree (*Melaleuca linariifolia*), white wood (*Atalaya hemiglauca*) and river oak (*Casuarina cunninghamiana*) dominated the tree stratum.

Experimental design

Six unburnt and 6 burnt plots were randomly located within the site. Plot boundaries were marked with numbered steel pickets and wooden pegs. Each plot was approximately 40 m² in size and the density of bellyache bush within these averaged 10 750 plants/ha. Fire was excluded from unburnt plots through placement of 20 m wide firebreaks, which involved removal of all trees and grass tussocks.

Fire treatments were applied annually in spring in 2 consecutive years: 15 September 1999 and 20 October 2000.

Plant mortality measurements

Prior to the application of treatments, all live bellyache bush plants within plots were marked with numbered pegs and classified into 3 life stages: juvenile, mature and old. Using a digital calliper, plants with a stem basal diameter ranging from 0.1–1.0 cm, 1.1–4.0 cm and >4.0 cm were classified as juvenile, mature and old, respectively. While most bellyache bush plants were partially foliated (5–10% leaf cover) at the time of recording, live plants could be readily identified as they exuded a colourless latex when struck with a sharp knife at the base of the stem and the characteristic colour of the internal parts of the cut bark was green.

Plant mortality was documented following each fire. This involved initially checking plants for exudate and the green colour of cut bark 2 weeks after burning, and confirming these results a year later once surviving plants had sufficient time to grow.

Post-fire seedling recruitment

In each plot, 2 randomly located 0.5 m × 0.5 m quadrats were permanently established in the centre of the plot after the burn, and subsequent seed germination was monitored, for determination of seedling emergence patterns and seedling density changes. Measurements commenced at the time of treatment implementation and continued on a monthly basis until June 2001 (21 months after the first fire). Measurements of seedling emergence involved counting and removing all seedlings from within 1 of the 2 quadrats at each recording period. Monthly observations were sufficient to ensure that all emerging seedlings were counted before any died and desiccated. Seedling survival and density were determined in the remaining quadrat, by counting the number of seedlings present at each recording time.

Fire behaviour

For both fires, fuel load and soil moisture content of the site were estimated on the day of burning. Soil moisture content was determined gravimetrically from 36 randomly selected soil samples (0–5 cm depth below the litter layer) and fuel

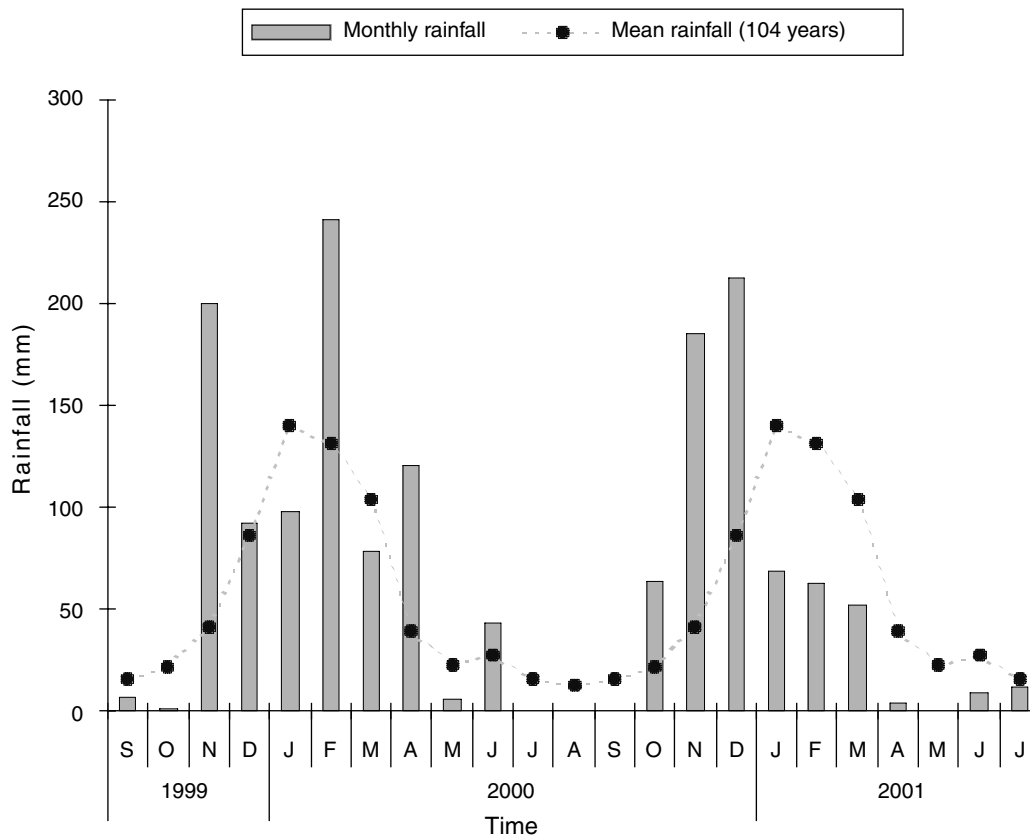


Figure 1. Monthly rainfall from September 1999–July 2001 and long-term mean rainfall (104 years) at Charters Towers.

load was estimated by removing all above-ground plant material from 48 randomly placed 0.2 m² quadrats. Samples for soil moisture and fuel load were placed in waterproof plastic bags and transferred to the laboratory where their fresh weight was determined. Samples were then oven-dried (80°C and 105°C for 48 h for the fuel load and soil moisture samples, respectively), their dry weights recorded and gravimetric soil moisture and fuel moisture levels calculated (Table 1).

Table 1. Site conditions (\pm s.e.) during the first and second fires at 'Shilo', Charters Towers.

Variables	First fire	Second fire
Fuel load (t/ha)	9.5 \pm 3.5	9.5 \pm 6.5
Fuel moisture (%)	16.9 \pm 5.0	10.0 \pm 2.8
Soil moisture (%) (0–5 cm)	1.4 \pm 0.5	0.9 \pm 0.6
Ambient temperature (°C)	35.2 \pm 2.0	37.1 \pm 3.0
Relative humidity (%)	19.7 \pm 2.1	20.6 \pm 4.4
Wind speed (km/h)	6.1 \pm 1.9	4.2 \pm 1.1

Climatic conditions were recorded on the day of burning immediately before ignition. Variables recorded included ambient temperature, relative humidity, wind speed and wind direction (Table 1).

Temperatures of fires were measured by placing 2 type K steel-encased thermocouples at 6 positions (3 above-ground and 3 below-ground; 150 cm, 50 cm, 0 cm, –0.5 cm, –1.0 cm and –2.0 cm) within the vertical profile where bellyache bush plants were located. The data collected from the thermocouples were stored in data loggers (Data Electronics Pty Ltd) buried underground during the fire. Duration of maximum temperature was the length of time during which temperatures within 5% of the maximum were recorded.

Fires were lit close to mid-day in order to maximise uniformity in fire behaviour over the site; using drip torches to promote a continuous fire line. All fuel was burnt as head fires following an initial back burn phase on the north-eastern corner of the site.

Data analysis

For all parameters measured, paired t-tests (Steel and Torrie 1980) were used to analyse for differences between burnt and unburnt treatments. Percentage data were arcsine-transformed prior to analysis. Back-transformed means appear in all plant mortality tables and figures. Correlation analysis was undertaken between fire-intensity parameters and temperatures reached within infestations at various heights above and below ground.

Results

Fire temperature and duration

The presence of a large dry fuel load combined with hot temperatures, low humidity and light wind (Table 1) resulted in high-intensity fires.

Temperatures recorded during burning varied within the vertical profile of the vegetation, ranging from 210–640°C (Table 2). Temperatures peaked at 640°C and 540°C during the first and second fires, respectively, at ground level, decreasing with increasing height above ground. A negative correlation was detected between fire temperature and height of thermocouple above ground ($r = -0.76$) and between duration of maximum temperature and height of sensors above ground ($r = -0.74$). A positive correlation was detected between fire temperature and duration ($r = 0.65$).

Plant mortality

Spring burning significantly ($P < 0.05$) decreased the density of the original bellyache bush population. The initial fire killed 76% of the plants

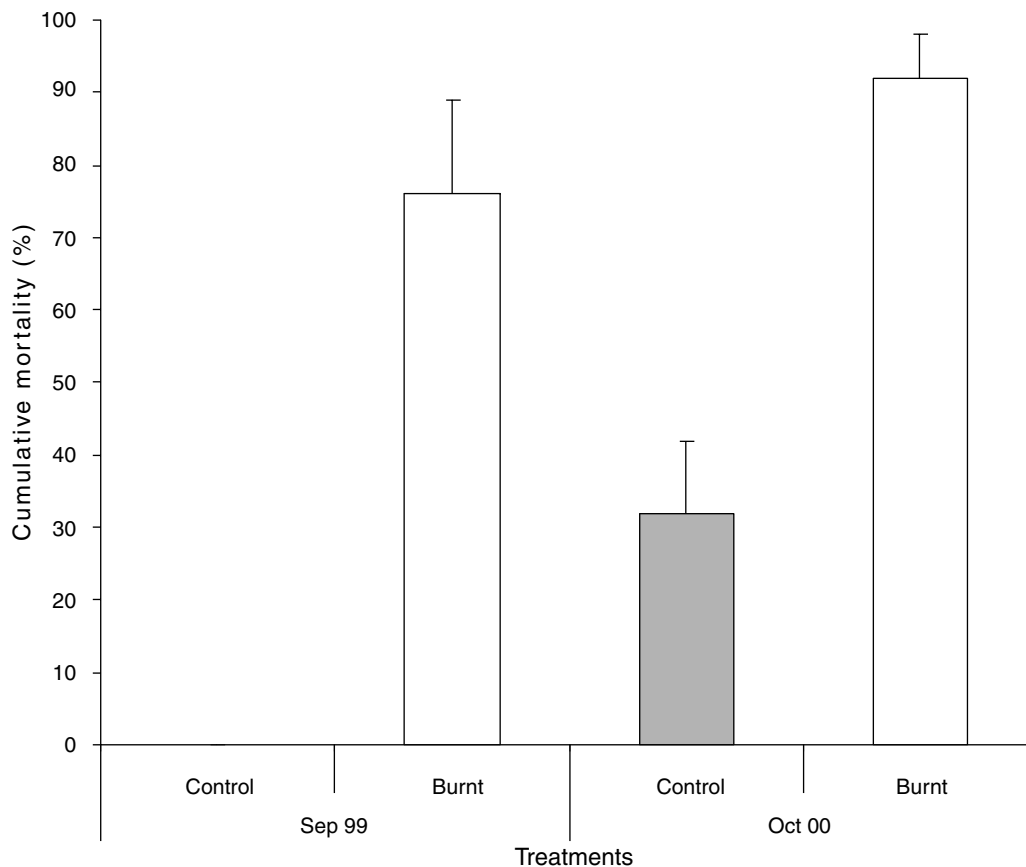


Figure 2. Cumulative mortality of original bellyache bush plants following spring burns in September 1999 and October 2000. Vertical bars indicate the s.e. of the mean.

present at the commencement of the study compared with nil mortality in the unburnt controls. The second burn, implemented a year later, extended the kill rate to 92% (Figure 2). In contrast, mortality in control plots peaked at 32% (Figure 2).

The proportions of juvenile, mature and old bellyache bush plants in the population were also significantly ($P < 0.05$) affected by fire. Juvenile plants were more sensitive to fire than mature or old plants (Figure 3). Following the second fire, mortality of juvenile, mature and old bellyache bush plants averaged 100, 93 and 73%, respectively. In comparison, mortality in control plots for juvenile, mature and old bellyache bush plants averaged 55, 24 and 21%, respectively (Figure 3).

Table 2. Maximum temperature and duration at 150 cm, 50 cm, 0 cm, -0.5 cm, -1.0 cm and -2.0 cm from ground level within the vertical profile of the bellyache bush vegetation.

Fire treatments	Thermocouples placement position					
	150 cm	50 cm	0 cm	-0.5 cm	-1.0 cm	-2.0 cm
	Temperature (°C)					
First fire	310	340	640	88	94	50
Second fire	210	240	540	63	30	25
	Duration ¹ (seconds)					
First fire	6	12	12	93	53	48
Second fire	3	9	30	63	66	85

¹ Length of time during which temperatures within 5% of the maximum were recorded.

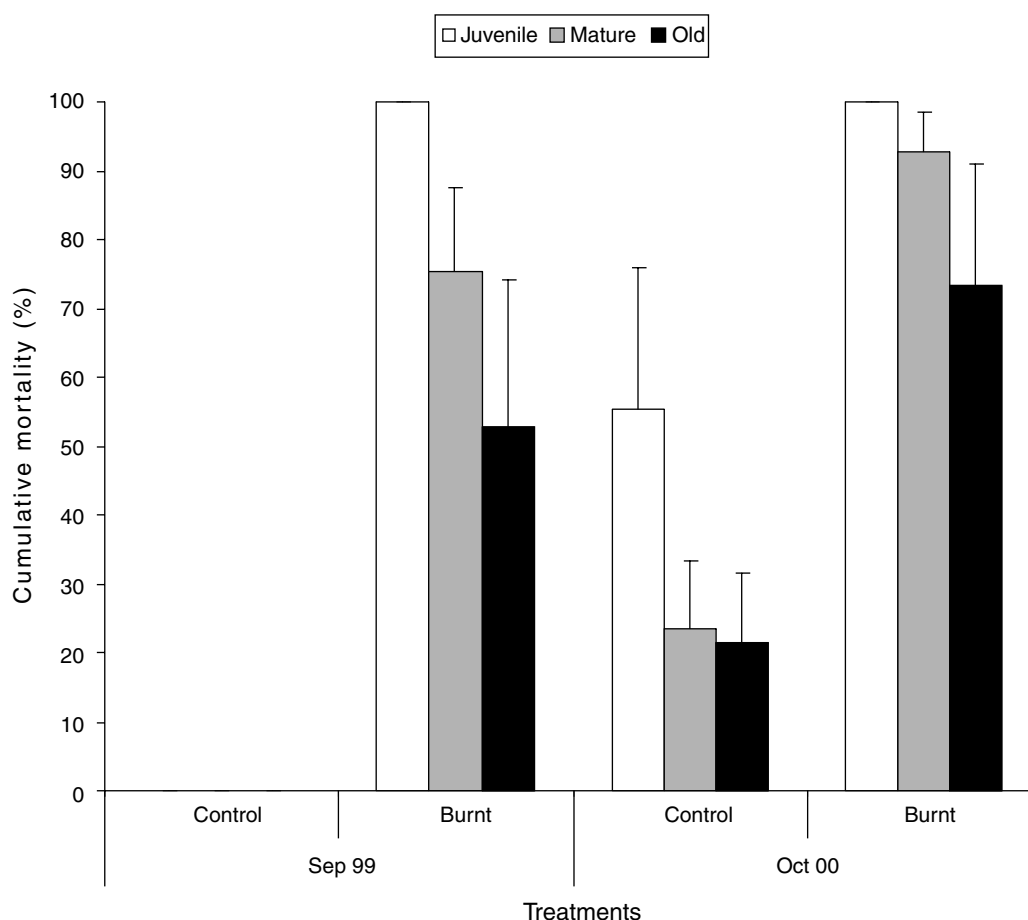


Figure 3. Cumulative mortality of original juvenile, mature and old bellyache bush plants following spring burns in September 1999 and October 2000. Vertical bars indicate the s.e. of the mean.

Post-fire recruitment

A significant difference ($P < 0.05$) in seedling emergence occurred between burnt and unburnt treatments following the first fire, but not the second.

Above-average rainfall 2 months after the first fire (200 mm fell in November 1999) produced a 1.7-fold increase in seedling emergence in burnt plots compared with the unburnt controls (5.4 vs 1.9×10^6 seedlings/ha) (Figure 4). Despite continued above-average rainfall (Figure 1) over the ensuing wet season (1999–2000), no further emergence occurred until commencement of the next wet season. Following the second burn in October 2000, more than 470 mm of rain fell on the site over the following 2 months. Subsequent seedling emergence averaged 672 000 seedlings per ha regardless of treatments imposed.

Increased seedling emergence led to a significantly ($P < 0.05$) higher density of bellyache bush

seedlings in burnt plots than in unburnt controls (Figure 5). Even after high mortality occurred over the wet season of 2000, some 430 000 seedlings per ha were present in burnt plots prior to implementation of the second fire, compared with 80 000 seedlings per ha in the unburnt controls. Similarly, at the end of the study, seedling density in burnt and unburnt treatments averaged 368 000 and 40 000 plants per ha, respectively.

Discussion

Bellyache bush plants proved highly susceptible to fire, particularly during the juvenile stage. Even so, two successive annual spring burns were necessary before 90% of the original population were killed, even with good fuel loads and ideal conditions for burning.

In contrast to the deleterious impact on existing bellyache bush plants, fire stimulated

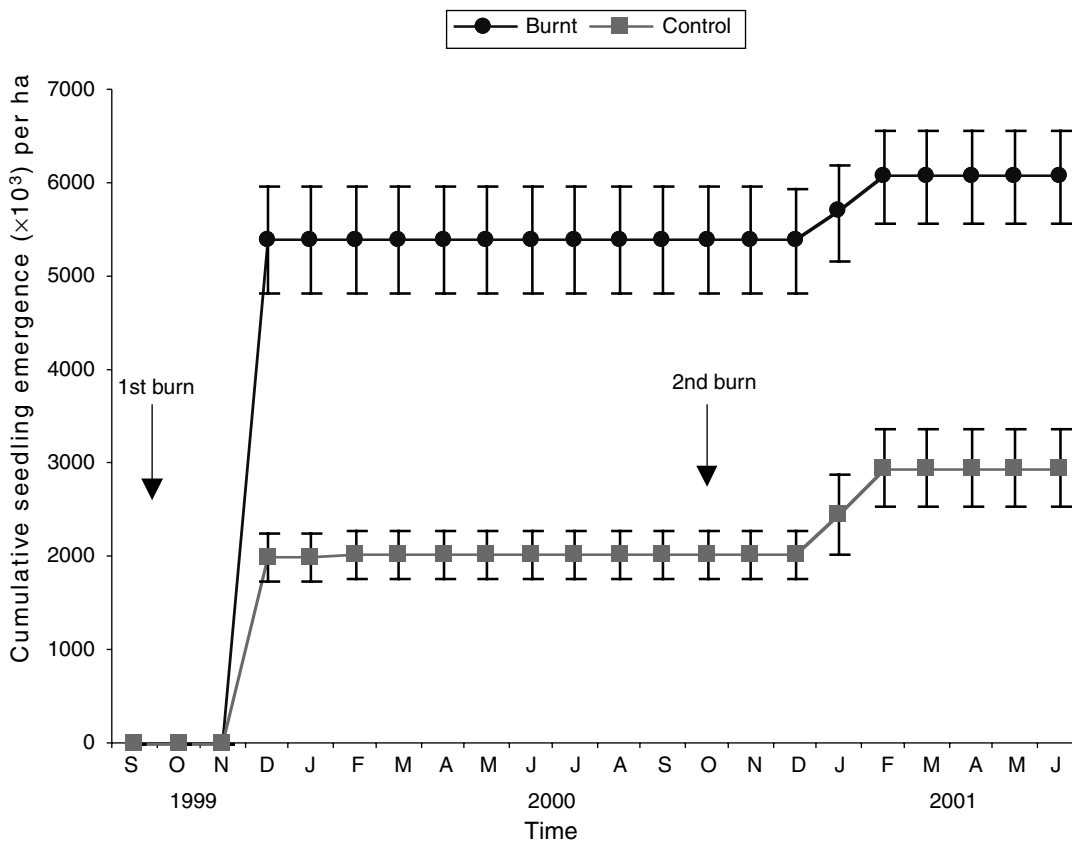


Figure 4. Cumulative seedling emergence in burnt and unburnt treatments following spring burns in September 1999 and October 2000. Vertical bars indicate the s.e. of the mean.

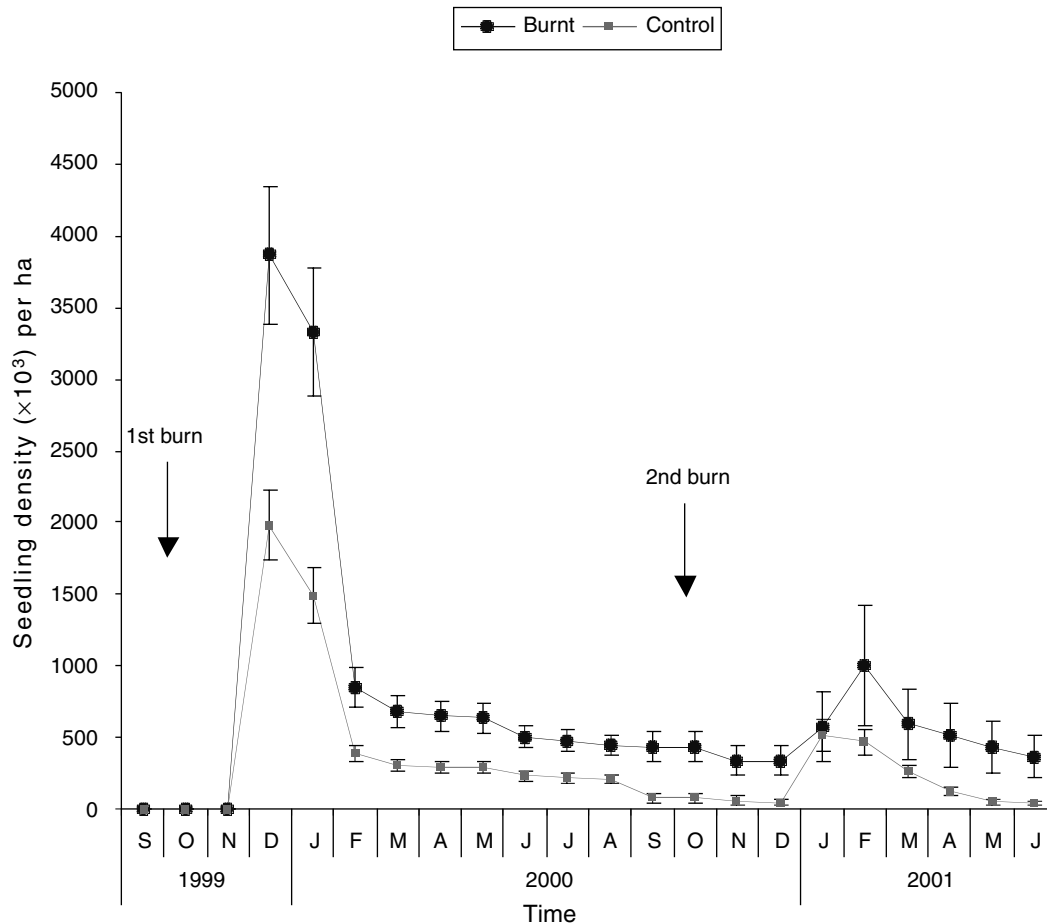


Figure 5. Monthly seedling density of bellyache bush in burnt and unburnt (control) treatments as affected by spring burns in September 1999 and October 2000. Vertical bars indicate the s.e. of the mean.

post-fire seedling emergence. Markedly more seedlings emerged in burnt plots than in the unburnt controls. Even though the majority of these seedlings died within the first 13 months under the prevailing environmental conditions, there is clearly potential for large-scale recruitment to occur after burning, as is the situation following the application of herbicides (J.S. Vitelli, personal communication).

For both fires undertaken in this study, weather, soil and fuel characteristics were conducive to hot burns. Maximum temperatures reached 640°C and 540°C for the first and second fires, respectively. Hopkins (1965) recorded soil surface temperatures in excess of 538°C following burning during the early part of the dry season. Similarly, Masson (1954), in a heavy stand of grass in West Africa, recorded soil

surface temperatures during a burn as high as 720°C. While exposure of bellyache bush to such high temperatures failed to ignite stems, it caused them to ooze caramelised latex and blister profusely. Such responses are not surprising, given the high sugar concentration (24% sucrose) in its latex (Bebawi and Campbell 2002c).

Mortality of bellyache bush was quite variable over the site and was directly related to the available fuel load when the fire was lit. As such, pre-fire grazing management that allows a buildup of fuel should maximise the level of mortality. Difficulties will arise with very dense infestations of bellyache bush, as we have observed that grass is precluded, irrespective of grazing practices.

The high seedling emergence recorded after the first fire was unexpected, as the temperature reached at the soil surface (640°C) was expected

to kill most seeds (Bebawi and Campbell 2002b). We could only speculate that seedling emergence occurred from seeds buried in the soil. A recent study has confirmed that this is probably the case as 73% of bellyache bush seeds were buried more than 1 cm below ground (Bebawi and Campbell 2002b). At such depths, most of these seeds would escape exposure to lethal temperatures as indicated by our temperature recordings in the soil. Bellyache bush seeds are larger (24–20 mm²) and heavier (60–40 mg) (F.F. Bebawi, unpublished data) than seed of other weeds, such as rubber vine (4.2–4.8 mm²; 9–8 mg) (Bebawi and Campbell 2000). The possibility exists that the large size and weight of bellyache bush seeds may also play a part in protecting them from lethal temperatures.

The reason for the increased seedling emergence of bellyache bush in burnt plots remains to be clarified. Possible contributing factors include direct effects that stimulate seeds to germinate and indirect effects that provide a more favourable environment for germination to occur, such as the removal of competition or shading. Direct effects following burning are generally attributed to the exposure of seeds to either high temperatures (Martin *et al.* 1975; Hanes 1977; Jeffrey *et al.* 1988; Thanos and Georghiou 1988; Doussi and Thanos 1994) or plant-derived smoke (De Lange and Boucher 1990; Baxter *et al.* 1994; Roche *et al.* 1998).

Even with the high mortality of bellyache bush seedlings which occurred, the population in burnt plots at the end of the study was 368 000 seedlings per ha. This would appear to be more than enough to cause reinfestation of a site if no further control activities were implemented.

These results clearly indicate that further work is needed to investigate integrated control methods (fire, chemical, mechanical and bio-control) that maximise control of bellyache bush populations, while minimising negative environmental impacts. Before fires are implemented in riparian habitats, consideration should be given to the native plant species present and the impact that imposed fire regimes may have on them. In areas where there are highly susceptible species, alternatives such as slashing may be more appropriate. If fire is employed, it is essential that action is taken to control the mass of seedlings, which will inevitably emerge.

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