Research Note

Chaining and Burning Modifies Vegetation Structure, Fuel, and Post-Disturbance Sprouting Capacity

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Abstract

Prescribed fire and/or mechanical methods can be used to modify the quantity, continuity, and/or spatial arrangement of flammable fuel. Yet the consequences of fuel management, both in terms of ecological outcomes and in facilitating improved fire management, often are poorly documented. In the global biodiversity hotspot of southwest Western Australia, chaining and burning is a novel technique for manipulating fuels. Vegetation first is dislodged using a chain, then after a period of curing, burnt. We tested whether combining two disturbance events in this way results in different vegetation structure postfire than only burning, and whether the postfire sprouting capacity of community-dominant *Eucalyptus* spp. is compromised. Both chained and burnt and only burnt treatments had much less leaf litter and vegetation >25 cm high than long-unburnt vegetation, indicating a fire management benefit of fuel modification. Chained and burnt strips had a threefold reduction in standing dead vegetation compared to only burnt samples. The stem number of *Eucalyptus* spp. was reduced by 20% in chained and burnt strips compared to only burnt vegetation, indicating that consecutive disturbances reduce resilience and might render sprouters vulnerable to subsequent disturbances. Balancing the fire management benefits of chaining and burning with the ecological consequences is a significant challenge facing land managers in this fire-prone landscape.

Resumen

Las quemas prescritas y/o los métodos mecánicos pueden utilizarse para modificar la cantidad, continuidad y/o el arreglo especial del combustible inflamable. Sin embargo, las consecuencias de manejo del combustible, tanto en términos de resultados ecológicos como en facilitar el buen manejo del fuego, son a menudo mal documentados. En la zona interactiva de la biodiversidad global del sureste de Australia Occidental el cadeneo y la quema son técnicas nuevas para manipular el combustible. Primero se quebró la vegetación utilizando una cadena, y después de un periodo se quemó. Experimentamos si la combinación de dos eventos de disturbio de esta manera resulta en una vegetación diferente en estructura después de la quema, utilizando únicamente fuego, y si se pone en peligro la capacidad de rebrote después del fuego de la comunidad dominante de *Eucalyptus* spp. En la combinación de los tratamientos, cadeneo y quema, así como en el tratamiento de la quema únicamente, se encontró menos material foliar y vegetación mayor de 25 cm de altura que en las áreas si quemar, indicando que el manejo del fuego beneficia la modificación del combustible. Las líneas de las quemas y cadeneo se encontró una reducción triple en vegetación muerta comparada con las áreas donde se usó quema únicamente. El numero de tallos de *Eucalyptus* spp. se redujo en un 20% en las líneas donde se utilizó el cadeneo y la quema en comparación donde se usó la quema únicamente, indicando que los disturbios consecutivos reducen la capacidad de recuperación y pueden hacer los rebrotes vulnerables a disturbios posteriores. Equilibrar los beneficios del manejo del fuego, con el cadeneo y la quema con las consecuencias ecológicas es un gran tarea que enfrentan los manejadores del recurso en estas áreas que están propensas al fuego.

Key Words: *Eucalyptus*, fire ecology, fire management, mallee, prescribed burning, resprout

INTRODUCTION

In landscapes that are prone to fire, land managers can be faced with competing fire management objectives. These can include protection of human life and property and biodiversity conservation (Morrison et al. 1996), and conserving biota with divergent responses to fire (Burrows and Abbott 2003). Although the overall objectives of, and the techniques used in, fire management programs vary with the social and environmental context in which decisions are made, modifying the quantity, continuity and/or arrangement of available flammable fuel is a common approach (Burrows 2008). The aims of fuel modification include reducing the severity of wildfires and increasing opportunities for fire suppression (Burrows 2008). Modified-fuel zones have proven effective in reducing the impact of wildfires at a variety of scales (Fernandes and Botelho 2003), although not in all ecosystems and/or conditions (Price et al. 2007).

Mechanical methods, such as slashing or thinning, and prescribed fire, either singularly or in combination, are the

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predominant approaches to modifying available fuel. Applying mechanical disturbance and fire in succession is predicted to have different effects on vegetation structure and the response of plants compared to no disturbance, or the singular disturbance of only burning. Multiple disturbances differentially affect the persistence of plant functional types defined by postfire regenerative traits. Obligate seeders are typically highly susceptible, whereas sprouters often are more resilient, although resprouting capacity and survival can be affected (Noble 2001; Vilà-Cabrera et al. 2008; Gosper et al. 2010).

Southwest Western Australia (WA) is a globally significant hotspot for plant diversity and endemism that has evolved under the influence of recurrent fire (Burrows and Abbott 2003). Constructed firebreaks are an important tool in fire management in native vegetation, with chained and burnt strips being one type of firebreak widely used in heath and mallee (multi-stemmed *Eucalyptus* spp. that resprout from lignotubers following fire) communities. Strips are chained, breaking off or uprooting most stems $> \sim 0.5$ m in height, and at a later date, burnt.

Chaining and burning has been in use in WA since at least the 1980s (McCaw and Smith 1992) and is used on other Mediterranean-climate vegetation (Esplin et al. 2003), but until recently the ecological impacts were largely unknown. Gosper et al. (2010) showed that chaining and burning reduced plant species richness and recruitment of serotinous obligate seeders compared to burning alone. However, there has been little research quantifying the effects of chaining and burning on vegetation structure, flammable fuels, and resilience of sprouters (Gosper et al. 2010). To help inform fire management decisions, we compared outcomes of chaining and burning with outcomes of only burning and no disturbance, to determine the 1) relative impacts on vegetation structure and flammable fuels; and 2) relative effects on sprouting capacity in mallees, a community-dominant group of sprouters.

METHODS

The study was conducted in Lake Magenta and Dunn Rock Nature Reserves, and adjoining unvested crown land, south of Newdegate (lat 33°04′S, long 119°04′E) in southwest WA. The region has a Dry Mediterranean climate, with approximately 350 mm annual rainfall (52% falling May to August), a mean monthly daily temperature maxima range of 15.4–31.4°C and minima range of 5.5–15.2°C. This study utilized three chained strips burnt a variable length of time (~1 to 17 mo) after chaining. Although the time period between chaining and burning is variable between locations, all periods are short compared to natural disturbance frequencies (Parsons and Gosper, in press). Fires sometimes passed from the chained strip into unchained vegetation, but in other places it did not, providing the opportunity to sample treatments in close spatial proximity.

Experimental Design

Three representative tallerack (*Eucalyptus pleurocarpa* Schauer) mallee–heath areas that contained the three treatments (chained and burnt, burnt only, and "unburnt"—i.e., 35+ yr postfire) were selected for study. Chaining and/or burning occurred in different years (2001, 2003, 2005) in each area; hence time since disturbance, location, and event-dependent effects were confounded (as is typical of chronosequence approaches). This factor is termed "year" hereafter. Each year contained four blocks placed at random, but at least 150 m apart, each with a randomly placed 100-m transect and a 10×10 m plot per treatment, leading to a three-fire treatment $\times$ 3-yr $\times$ four-block (nested within year) experimental design ($n = 36$ transects/plot; see Gosper et al. 2010 for further details).

Measuring Vegetation Structure

Vegetation structure was measured at two spatial scales. First, along each transect, a 4-m high pole divided into intervals (see Table 1) was placed systematically every 2 m (totalling 50 per transect), recording the presence or absence of live and dead vegetation intercepting each height division. Litter cover was quantified by recording the presence or absence of litter at point observations 1 m to either side of the 50 pole placements ($n = 100$ per transect). Second, in the 10×10 m plot, vegetation intercepts were recorded as above at 50 points placed 1 m apart along five lines placed in parallel across the plot. Point intercepts from the two methods were combined ($n = 100$) to calculate the proportion of intercepts in each height class. Vegetation and litter point intercepts are strongly correlated with fuel loadings in mallee–heath (McCaw 1997), and hence were used as a surrogate for direct fuel measurements.

At 10-m intervals (totalling 10 per transect), the diameter at breast height (dbh) of all stems of the nearest individual mallee *Eucalyptus* spp. was measured. From these measurements, we calculated total cross-sectional area (CSA), mean stem dbh, maximum stem dbh, and the number of stems per mallee. All measurements were taken during 2008.

Statistical Analysis

Differences in the overall vegetation profile (vegetation intercepts in each height category and of litter) were tested by multivariate analysis of the block design in permutational analysis of variance (PERMANOVA), after testing for homogeny of dispersions (PERMDISP; Anderson et al. 2008).

Differences in individual vegetation structural variables between chained and burnt and only burnt treatments were determined using analysis of variance (STATISTICA; StatSoft 2005) on the block design. Analyses were completed using combined live and standing dead vegetation intercepts, then repeated with dead vegetation excluded where significant treatment effects were detected. Transformations were required to homogenize some variances: square root $(x+1)$ for mallee stem number, natural log $(x+1)$ for all mallee stem size measurements, and arcsin (of square root) for intercepts with standing dead vegetation.

RESULTS

The distribution and quantity of vegetation across the vegetation profile differed among treatments, but dispersion did not. A significant treatment by year interaction was detected in PERMANOVA (Table 1), with both recently

Table 1. Permutational analysis of variance and analysis of variance tests of the effects of chaining and burning and burning only on the vegetation profile, intercepts with live and dead vegetation and litter, and mallee stem number and size.

	Mean ± SE			F (or pseudo-F)			
Whole profile	Chain + burn	Burn only	Unburnt	Treat	Year	Block (Y)	T × Y
PERMANOVA			(df)	(2,18)	(2,9)	(9,18)	(4,18)
				35.6***	7.2**	1.9**	4.3***[1]
PERMDISP			(df)	(2,33)	(2,33)	(11,24)	
Dispersion	13.4 ± 1.4	14.0 ± 1.8	9.8 ± 0.6	2.86	13.5***	2.10	

	Mean ± SE		F value				
	Chain+burn	Burn only	Treat	Year	Block (Y)	T × Y	T × B (Y)
Proportion of intercepts with all vegetation		(df)	(1,9)	(2,9)	(9,9)	(2,9)	
0–12 cm	0.65 ± 0.03	0.66 ± 0.04	0.12	8.39** (3 < 5 = 7)[2]	2.74	0.49	
12–25 cm	0.52 ± 0.04	0.52 ± 0.05	0.01	22.7*** (3 < 7 < 5)	1.13	0.54	
25–50 cm	0.30 ± 0.04	0.35 ± 0.03	3.00	10.7** (3 = 7 < 5)	1.94	0.85	
50–100 cm	0.10 ± 0.02	0.18 ± 0.02	7.69*	0.27	0.90	1.96	
100–200 cm	0.04 ± 0.02	0.09 ± 0.01	10.0*	3.02	1.11	3.63	
200–400 cm	0.00 ± 0.00	0.01 ± 0.01	------------Insufficient intercepts for analysis------------				
Dead	0.08 ± 0.03	0.24 ± 0.05	56.8***	19.2*** (7 < 5 < 3)	2.27	1.54	
Veg. absent	0.21 ± 0.03	0.18 ± 0.03	2.00	10.5** (7 = 5 < 3)	1.66	0.26	
Leaf litter	0.41 ± 0.03	0.43 ± 0.02	0.81	9.99** (3 < 5 = 7)	1.90	3.02	
Proportion of intercepts with live vegetation							
50–100 cm	0.09 ± 0.02	0.09 ± 0.01	0.03	9.32** (3 < 5 = 7)	0.83	0.02	
100–200 cm	0.04 ± 0.02	0.05 ± 0.01	0.90	10.3** (3 = 5 < 7)	1.58	0.58	
Mallee		(df)	(1,9)	(2,9)	(9,216)	(2,9)	(9,216)
Stem number	3.94 ± 0.46	4.98 ± 0.51	5.23*	11.4** (3 = 5 < 7)	2.34*	1.71	0.71
Stem dbh[3] (cm)	0.96 ± 0.10	1.04 ± 0.09	1.77	21.3*** (3 < 5 < 7)	2.27*	2.21	0.99
Max. dbh (cm)	1.32 ± 0.14	1.43 ± 0.13	1.59	17.7*** (3 = 5 < 7)	2.16*	2.17	0.92
Total CSA[3] (cm^2)	15.9 ± 2.63	16.7 ± 2.66	2.98	21.2*** (3 = 5 < 7)	2.15*	2.12	0.89

[1]In pairwise comparisons, in all years, chained and burnt = only burnt ≠ unburnt.
[2]Posthoc Newman–Keuls test differences between years post-disturbance. *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.
[3]dbh indicates diameter at breast height; CSA, cross sectional area.

disturbed treatments being different from the unburnt treatment in all years in pair-wise comparisons. Recently disturbed vegetation had substantially less cover of litter and vegetation in taller (> 25 cm) height categories (Fig. 1). Chained and burnt was not distinct from only burnt vegetation, although differences were only marginally nonsignificant ($P < 0.1$) in two of the three years.

Among individual parameters, the most pronounced difference was in the greater cover of standing dead material in only burnt than chained and burnt vegetation (Table 1). Greater cover in the taller height categories (50–100 cm and 100–200 cm) in the only burnt treatment was mainly contributed by standing dead vegetation, because these strata were not significantly different when standing dead vegetation was excluded (Fig. 1; Table 1). No differences between treatments were detected in vegetation cover in lower height categories (< 50 cm), in the cover of litter, or in the proportion of points without intercepts with any vegetation.

Resprouting in mallees was affected by chaining and burning, with fewer stems at breast height per plant than in only burnt vegetation (Table 1). Due to the method of sampling stem number, this result could occur through having either fewer and/or shorter stems. Because the treatment × year interaction term was not significant, this suggests that reduced stem number is consistent across time and space and not restricted to the youngest transects where some stems were below breast height and thus not measured. There was a consistent nonsignificant trend for measures of mallee stem size (maximum and mean stem dbh and total CSA) to be lower in chained and burnt strips.

Pair-wise comparisons where a significant effect of year was detected indicated that live vegetation and litter cover and mallee attributes generally increased with time, and standing dead vegetation and points not intercepting vegetation decreased (Fig. 1; Table 1), a pattern consistent with differences for this confounded factor being driven primarily by time since disturbance.

DISCUSSION

Our results provide direct evidence for reduced resprouting capacity in mallees in chained and burnt compared to only burnt treatments, with fewer stems in chained and burnt strips

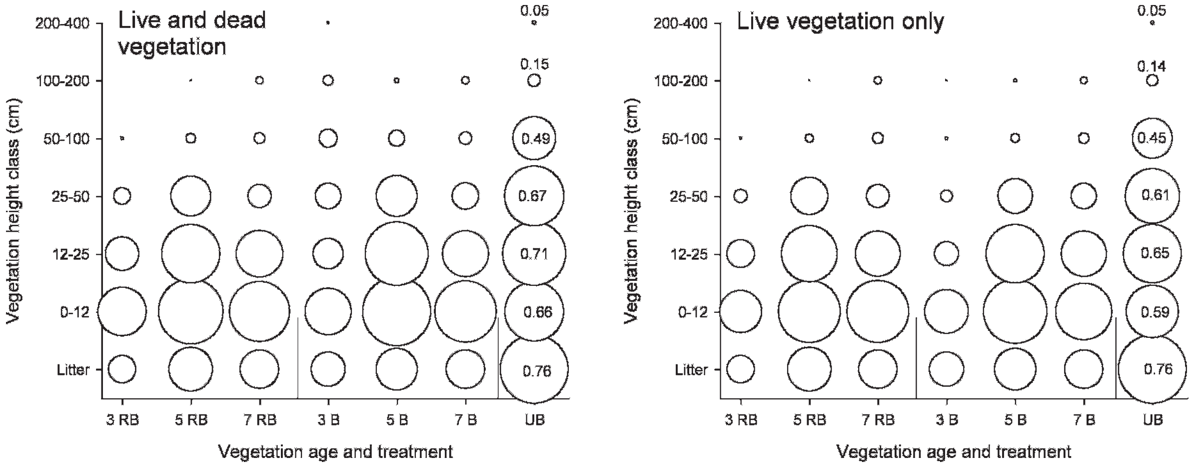

Figure 1. Mean proportional cover of litter and vegetation separated into height classes for chained and burnt (RB) and only burnt (B) treatments at three ages post-disturbance (3, 5, and 7 yr), and the unburnt (UB) treatment (variable age postfire, but >35 yr), with and without standing dead vegetation. Proportional cover is shown for the unburnt treatments for scale.

without any compensatory increase in stem size. Although multiple disturbances have been shown experimentally to affect the resilience of sprouters (Noble 2001), it rarely has been demonstrated as a consequence of management in natural systems (but see Vilà-Cabrera et al. 2008).

The long-term implications for vegetation composition and structure of event-driven reductions in sprouting capacity will depend on the length of time to the next disturbance causing sprout death (e.g., fire or chaining). The lengths of time mallees require to replenish lignotuber bud and/or carbohydrate stocks has barely been studied, but there is some evidence to suggest that capacity to resprout following defoliation declines as the interval between disturbances shortens. Noble (2001) showed that complete defoliation in three consecutive years resulted in 100% plant mortality. Yates et al. (2003) observed that the number of resprouting stems in mallees was similar following two fires 13 yr apart. Further research is needed to determine the length of time postchaining and burning that mallees might be vulnerable to further disturbances.

In some sprouters, stem numbers decline with increasing time since disturbance (Bond and Midgley 2001), a habit shared by many mallees (Noble 2001; Yates et al. 2003). Consequently, the number of stems per mallee in chained and burnt and only burnt treatments could be expected to converge over time, as recovering mallees shed stems.

Each of the treatments resulted in different vegetation structure. Because modifying vegetation structure is one of the aims of fuel reduction, such an outcome was expected. The temporal trends in vegetation structure after fire are typical of other studies, with vegetation and litter cover and plant size increasing with greater age post-disturbance and standing dead vegetation and open space decreasing from high levels immediately postfire (McCaw 1997; Baeza and Vallejo 2007). Combined application of mechanical methods and prescribed fire resulted in lower values for some vegetation structural parameters than only burning, as has been found elsewhere (Waldrop et al. 2008).

Chaining and burning is likely to confer some fire management advantages over only burning by resulting in less elevated and total fuel (through having less standing dead and live stems), which might facilitate application of prescribed burning in the initial years posttreatment through rendering fires easier to control. Similar live vegetation cover between treatments indicates that there would be minimal differences in available fine fuels (<6 mm in diameter; McCaw 1997), suggesting that the two fuel treatments are unlikely to differ greatly in their capacity to support spreading fires.

Both chained and burnt and only burnt vegetation contain substantially less total and elevated fuel through 7 yr post-disturbance and beyond than long-unburnt vegetation (Fig. 1; McCaw 1997). These fuel reduction treatments thus presumably confer some opportunity for successful fire suppression in nonextreme conditions, or more safely initiating fire in more extreme conditions, such as during back-burning operations. By 7 yr post-disturbance, both treatments are likely to be able to support spreading fires, due to the rates of fuel accumulation (Keith et al. 2002).

MANAGEMENT IMPLICATIONS

Chaining and burning reduces the total quantity of standing vegetative material compared to only burning, although the capacity of the two fuel treatments to support spreading fires might not differ. Operational decision-making could be improved by developing policy and criteria outlining the circumstances in which chaining and burning is appropriate, specifically where the relative benefits of chaining and burning in facilitating improved fire management outweigh the ecological costs, including a reduction in the resilience of mallees.

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