Impact of fire on rubber vine (*Cryptostegia grandiflora* R.Br.) and associated pasture and germinable seed bank in a sub-riparian habitat of north Queensland

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Summary
Effects of two annual late season fires on dense rubber vine (*Cryptostegia grandiflora* R.Br.) infesting a sub-riparian habitat in the dry tropics of north Queensland were investigated. Standing pasture biomass and quality and germinable seed bank of monocotyledons and dicotyledons (including rubber vine) were determined. The first fire significantly (P<0.05) reduced the rubber vine population by 80% (from 2560 plants ha^{-1} to 512 plants ha^{-1}). A second fire a year later extended the kill rate to 99% (to 18 plants ha^{-1}). The relative sensitivity to the imposed fire regime was juvenile >mature >old plants. No significant differences in standing pasture biomass occurred as a result of fire treatments. However, pasture quality was significantly improved after the first fire. Fire significantly affected the germinable seed bank of both dicotyledons and monocotyledons. The total germinable bank of dicotyledon and monocotyledon seeds was reduced by 52 and 78% after the first and second fire respectively. No rubber vine seeds were detected in the seed bank of either burnt or unburnt plots. We suggest that the present fire prescription may not only be a viable management method of reclaiming densely infested sub-riparian habitats but may also facilitate the use of mechanical or chemical control to clean up remnant infestations.

Introduction
Rubber vine (*Cryptostegia grandiflora* R.Br.) is an invasive woody weed of the dry tropics of northern Australia. It predominantly infests riparian habitats (Tomley 1995) but can also infest open pastures where the water table is high (Dale 1980). Dense infestations of rubber vine cause severe management problems for graziers. These problems include a reduction in pasture productivity, difficulties in mustering and the possibility of cattle deaths due to poisoning (McGavin 1969). It has been estimated that rubber vine costs primary industry in Queensland around $18 million per year (Mackey 1996).

Control methods for rubber vine include chemical, mechanical, biological, and fire control. The selection of the most appropriate method for a given situation (best practice) is dependent on its cost-effectiveness and the density and size of the particular infestation to be treated. For example, where rubber vine infestations exceed 2000 plants ha^{-1}, the use of fire is considered ‘best practice’ based on efficacy and economic considerations (Vitelli 1992).

Vitelli (1992) showed that, where there is sufficient dry fuel (2–9 tonnes dry weight ha^{-1}) to produce a fire hot enough to ignite green rubber vine, fire can kill 50–70% of plants, reduce the biomass of rubber vine and control seedling establishment and regrowth. He estimated that it cost 2.9–4.0 cents per plant to kill rubber vine by fire. Vitelli also found that a fuel load of 1 tonne per hectare would kill exposed seeds but mortality would drop to 2% if seeds were even slightly buried (0.5 cm). Recently, Grice (1997) found that fire killed about 96% of small plants (height >100 cm), 80% of medium-sized plants (height 100–199 cm) and 45% of large plants (height >200 cm) of rubber vine infesting an area of open woodland.

There is a body of evidence that indicates that fire is a natural part of the ecosystem in the northern savannas (Mott *et al.* 1985, Gill 1975). Prior to the use of the experimental site for cattle grazing, and later its infestation by rubber vine, it can be assumed that the area was burnt by periodic natural fires. The native plant species at the site would therefore be expected to have adaptations that allow them to survive fire, as mature plants, vegetative parts or seeds.

Most of the fire research on rubber vine has been conducted in open woodland situations. Little research has been done in riparian or sub-riparian zones in higher rainfall areas and at lower latitudes. The term sub-riparian is used in this study to describe riverine habitats that are subject to flooding during high river floods and are predominantly colonized by free-standing rubber vine plants. This contrasts with riparian habitats that are predominantly colonized by climbing rubber vine plants. Land managers who consider prescribed burning to control rubber vine in riparian zones lack information on its efficacy in these habitats. If informed rubber vine management by fire is to take place, land managers need to know how it affects both rubber vine and other biotic components of the habitat such as standing pasture biomass and germinable seed bank.

The objectives of this study were to:

i. evaluate the impact of two late season annual fires on dense rubber vine infesting a sub-riparian habitat in north Queensland, and
ii. determine the impact of these fires on standing pasture biomass and quality and germinable seed bank.

Materials and methods
Site description
The Australian Agricultural Company provided a 20 km^2 site on the cattle property Wrotham Park (S 16° 53" 94', E 143° 86" 49'), to undertake the fire study. Wrotham Park is located 114 km west of Chillagoe in the southern Cape York Peninsula, north Queensland. The site is known as Bullock’s Camp and is located between the north bank of the Walsh River and the southern face of Whiphandle Ridge. That paddock was ungrazed because of the rubber vine infestation and any cattle in it were wild cattle that could not be mustered.

The climate at the site was strongly seasonal, with almost no rain falling between May and October. The timing of the onset and cessation of rain varies between years. Total annual rainfall during 1997 and 1998 was 1064 mm and 920 mm respectively with 98% (978 mm) falling from December to March. Average monthly maximum temperature in summer is 36°C and an average monthly minimum temperature in winter is 15°C. The site was not deliberately burnt prior to this investigation within at least the last 12 years (Henry Burke, Land Manager of Wrotham Park, personal communication).

Botanically the site lies in the Monsoon Tall Grass Savanna (Mott *et al.* 1985) but had been highly modified by clearing and rubber vine invasion. The herbaceous vegetation was dominated by a mixture of native grasses that included: black spear grass (*Heteropogon contortus* (L.) P.Beauv. ex Roemer & Schultes), bull Mitchell grass (*Astrebla squarrosa* C.E.Hubb.), grader grass (*Themeda quadrivalvis* (L.) Kuntze), desert blue grass (*Bothriochloa ewartiana* (Domin) C.E.Hubb.), purpletop chloris (*Chloris inflata* Link), feathertop rhodes grass (*Chloris virgata* Sw.), fairy grass (*Sporobolus australasicus* Domin) and plume sorghum (*Sorghum plumosum* (R.Br.) P.Beauv.) in addition to the introduced buffel grass (*Cenchrus ciliaris* L.). The shrub stratum was dominated by rubber vine while a mixture of coolibah (*Eucalyptus coolibah* Blakely & Jacobs), bloodwood (*E. intermedia* R.T.Baker), black tea tree (*Melaleuca bracteata* F. Muell.), lancewood (*Acacia shirleyi* Maiden), beefwood (*Grevillea striata* R.Br.) and red bauhinia (*Lysiphyllum carronii* (F.Muell.) Pedley) dominated the tree stratum.

Soils are dark grey to black, very fine, self-mulching vertisols (Isbell 1996), with generally more than 60% clay in the surface soil. Local sorting and degradation of the surface soils has occurred where loss of groundcover has allowed water erosion to occur. As a result there are patches where the self-mulching properties of the soil has been impaired and there has been some loss of the colloidal fraction.

Experimental design

Six unburnt and six burnt plots each separated by a firebreak (4–12 m wide), were randomly located within the 20 km^2 site. Burnt plots were burnt twice in successive years, late in the dry season. Plot area averaged 240 m^2 and rubber vine density within these plots averaged 53 plants per plot giving an average 2560 plants ha^{-1}. This is considered dense according to Vitelli's (1995) rubber vine density classification system. The first fire was conducted on October 8, 1997 and a second fire approximately a year later on 16 September 1998. Plot boundaries were marked with numbered steel pickets and wooden pegs.

Rubber vine measurements

Although most rubber vine plants were leafless at the time of burning, live plants could be identified as these exude latex when struck with a sharp knife at the base of the stem. Live plants were individually tagged with numbered metal stakes.

On open woodland sites the shoot system of rubber vine is characterized by the presence of a relatively short main stem (<10 cm in height, personal observation of Faiz Bebawi) which subsequently bears several secondary stems (Curtis 1946, Grice 1996). In riparian zones the majority of the plants appear multi-stemmed at ground level, because the main stem is usually buried under silt. Since fire does not distinguish between main or secondary stems a standard system that classifies the rubber vine population into different life stages was developed.

The basal stem diameter was used as a criterion to identify life stages. The basal stem diameter is defined as the stem diameter at 30 cm above ground. A square ruler was used to determine the rectangular area occupied by a main stem or several secondary stems. The diagonal of this area represented the basal stem diameter. A normal distribution graph was then plotted using the two variables (number of stems and stem diameter per plant) as a criterion to identify three life stages. Plants with a stem basal diameter ranging from 0.1 to 2.0 cm, 2.1 to 30 cm and >30.1 cm were classified as juvenile, mature, and old, respectively.

Seed bank measurements

Ten surface soil samples (0–2 cm depth × 314 cm^2) were taken from each plot before and immediately after each fire treatment (that is before any rain had fallen on the burnt sites after the fire treatment concerned). Sampling was distributed over each plot to obtain soils representative of the plot. The soil samples were air-dried and bulked. Twelve sub-samples (1 kg each) were taken from this bulked sample and placed on perforated plastic pot trays (20 cm in diameter). These were watered to field capacity and soil moisture was maintained by covering the trays with a transparent plastic sheet to prevent evaporation. All trays were placed in a controlled environment glasshouse set at a day and night temperatures of 30±1 and 20±1°C respectively. Dicotyledonous, monocotyledonous and rubber vine seedlings were counted and removed fortnightly until no more seedlings emerged. The soil was allowed to dry, stirred and watered to field capacity and the procedure repeated. The process was carried out three times by which time no more seedling emergence was detected.

Fire measurements

Variables which influence fire behaviour were measured immediately prior to ignition on-site (Table 1). These included ambient temperature, relative humidity, wind speed and direction. Soil moisture content was determined gravimetrically from three soil samples (0–5 cm depth) randomly taken from each plot before site ignition. Fuel load was estimated from four randomly placed 0.5 × 0.5 m^2 quadrats within each plot before the fire was lit. All material (green and dead stem) was removed down to ground level. The fuel load samples were stored in waterproof plastic bags and transferred to the lab where their fresh weight was determined. The samples were then oven-dried (105°C for 48 h) and their dry weight recorded. Gravimetric fuel moisture content was then calculated.

Temperatures of fires were measured by placing 20 thermocouples at six vertical positions in two plots within the experimental site. Thermocouples measured fire temperatures at 0.5 cm below ground, on bare ground, below the fuel, above the fuel, on rubber vine crown, and 2 m above ground. The data collected from the thermocouples were stored in data loggers (Data Electronics Pty. Ltd.) buried underground during the fire.

Fires were lit close to the middle of the day in order to maximize uniformity in fire behaviour over the site. A drip torch was used to start the fire. Two burns were lit simultaneously, burning against the wind from the northern edge and with the wind from the southern edge. No action was taken to light patches that remained unburnt after the fire passed over the plot. The land manager accidentally burned one of the control plots in 1998.

Standing pasture biomass and quality measurements

The fuel load data also provided an estimate of standing pasture biomass. Pasture quality, which is presented in this study as SEV (Starch Equivalent Value), was determined from the oven-dried fuel samples using formula 1 below (Menke and Huss 1980). Analysis of crude protein, crude fat, crude fibre and N-free extract content of the dry pasture samples was done by the Department of Primary Industry Animal Research Institute, Moorooka, Queensland. The CFV (Chemical Fodder Value) derived by these methods was estimated using Klapp's 10-fodder value level system (Klapp 1965).

Formula 1: SEV= (crude protein (%) × 0.94) + (crude fat (%) × 1.91) + (N-free extract (%) × 1.0) + (crude fibre (%) × 1.0^A) - (crude fibre (%) × 0.58^A)

^{A} If the crude fibre (%) exceeds 16% multiply by 0.58, if it ranges between 14 and 16%; 12 and 14%; 10 and 12%, and 8 and 10% multiply by a factor of 0.48, 0.45, 0.38, and 0.34 respectively.

Data analysis

Paired t-tests (Steel and Torrie 1980) were used to analyse the differences between

Table 1. Site conditions during the first and second fire at Wrotham Park.

Burns	Air temp. (°C)	Relative humidity (%)	Wind speed (mph)	Wind direction	Conditions	Soil moisture (%)	Fuel moisture (%)	Fuel load (t ha^{-1})	Maximum fire temp. (°C)
1997	36.0–48.8	38–45	1.3–3.9	SE	Clear	1.2–3.0	4.5–8.9	2.0–7.6	675
1998	37.4–46.1	10–26	2.8–9.2	SE	Clear	0.6–1.7	4.3–8.9	4.0–8.5	681

Table 2. Means of monthly maximum temperature, minimum temperature and rainfall and mean fire temperature in 1997 and 1998. Values followed by the same letter are not significantly different at P<0.05.

Year	Mean monthly air temperature (°C)		Mean monthly rainfall (mm)
	maximum	minimum	
1997	32.2 a	19.0 b	88.7 a
1998	32.4 a	20.4 a	76.7 a

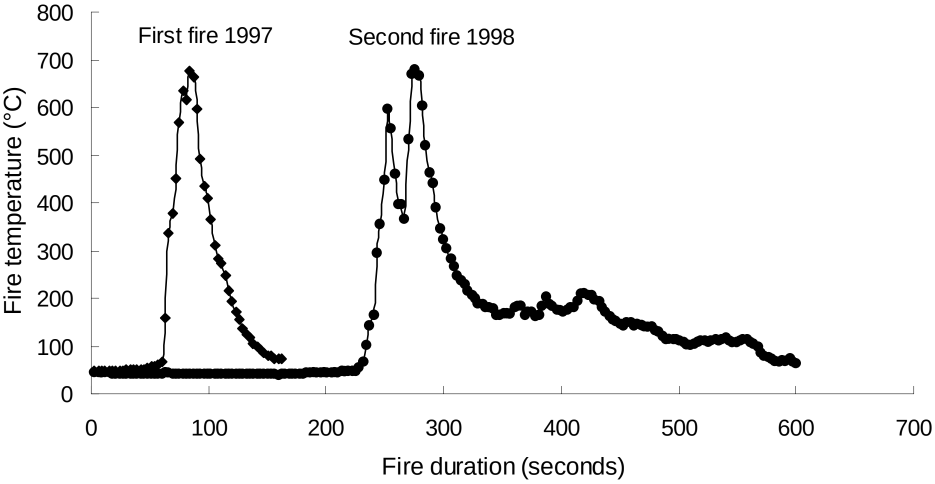

Figure 1. Temperature at 2 m above ground during the first and second fire.

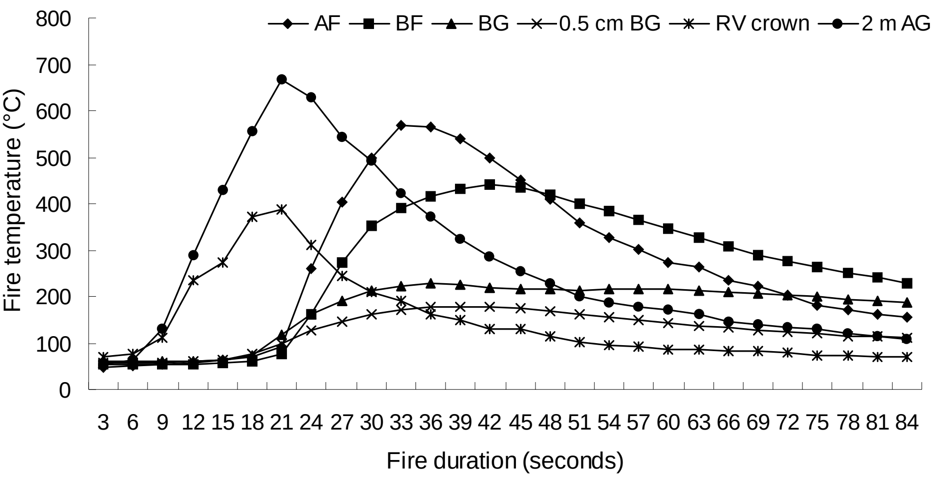

Figure 2. Fire temperature at 0.5 cm below ground (0.5 cm BG), on bare ground (BG), below fuel (BF), above fuel (AF), on rubber vine crown (RV crown), and 2 m above ground (2 m AG) in 1997.

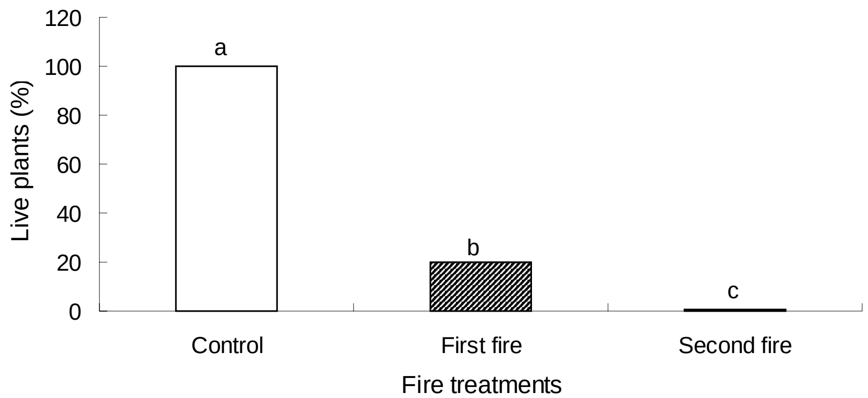

Figure 3. Response of rubber vine plants to fire treatments. Columns associated with the same letter are not significantly different at P<0.05.

burnt and unburnt treatments in all the above measurements. Percentages were arcsine transformed prior to statistical analysis and later back-transformed. Untransformed data appear in all tables and figures. Statistical evaluation of population sensitivity to fire was performed by regression analysis using the regression coefficient 'b' in a Finlay and Wilkinson (1963) style analysis, regressing each life stage total (juvenile, mature and old) on overall population total (juvenile + mature + old rubber vine plants). In such an analysis a regression coefficient value of 1.0 indicates average sensitivity whereas values >1.0 indicate low sensitivity and values <1.0 indicate high sensitivity.

Results

Burning was undertaken a month earlier (in September) in 1998 than in 1997 because of the early onset of the rainy season. No significant differences (P>0.05) in mean monthly air maximum temperature and mean monthly rainfall were detected between 1997 and 1998 whereas mean monthly air minimum temperature was significantly higher in 1998 compared with that in 1997 (Table 2). Although maximum fire temperature recorded in the first fire (675°C) was nearly equal to that of the second fire (681°C) (Table 1), the duration of these temperatures was much longer with the second fire (Figure 1). This may be attributed to the lower air relative humidity, lower soil moisture and higher fuel load for the second fire when compared with the first fire (Table 1). Maximum temperatures recorded 0.5 cm below ground and in the vertical profile of the fire ranged between 179 and 674°C in 1997 (Figure 2).

Fire significantly (P<0.05) reduced the rubber vine population by 80% during the first fire when compared with the control (Figure 3). A second fire a year later extended the kill rate to 99.3%. The proportions of juvenile, mature and old rubber vine plants in the population were also significantly (P<0.05) affected by fire (Figure 4). Juvenile plants were more sensitive to fire than mature or old plants. They exhibited a regression coefficient of 0.71 and were completely removed from the population after the first fire. Mature plants were less sensitive to fire than juvenile plants. Their regression coefficient was 0.26. Their population was reduced from 70.4% before burning to 10.7% after the first fire to nil percent after the second fire. The old plants were least sensitive. They exhibited a regression coefficient of 0.02. Their population was reduced from 27.2% before burning to 9% after the first fire to 0.72% after the second fire when compared with their initial population (Figure 4).

No significant differences (P>0.05) in standing pasture biomass were detected between fire treatments. However, standing pasture biomass quality significantly (P<0.01) increased by 6.1% after the first fire when compared with the control.

The total germinable seed bank (dicotyledons plus monocotyledons) averaged 29 million seeds per hectare with monocotyledons comprising 97% of the total seed bank (Figure 5). However, the total germinable seed bank was significantly affected by fire (Figure 5), being reduced by 52 and 78% after the first and second fire respectively when compared with that of the control. No significant differences (P<0.05) were detected in germinable dicotyledon seeds between the first and second fire (Figure 5). No germinable rubber vine seeds were detected among the dicotyledon seeds. Highly significant differences (P<0.01) in germinable monocotyledon seeds were detected between the first and second fire. Reductions in the monocotyledon seeds alone averaged 53 and 79% after the first and second fire respectively when compared with that of the control (Figure 5).

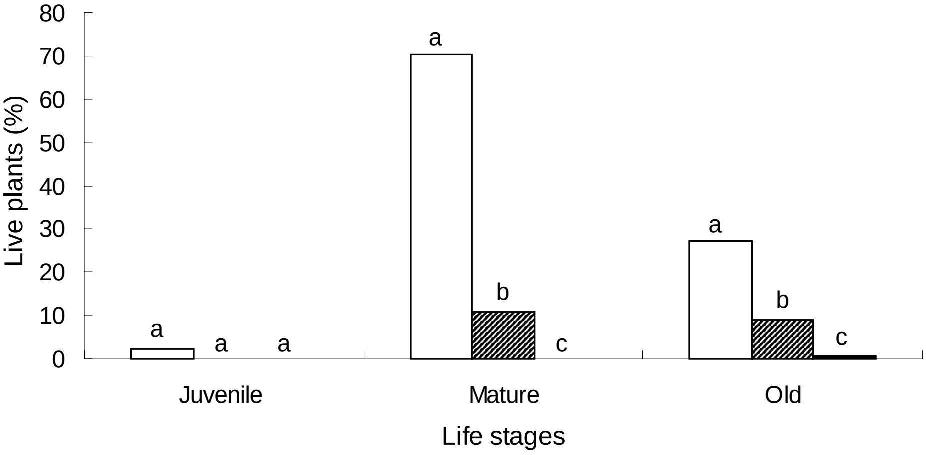

Figure 4. Response of juvenile, mature and old rubber vine plants to fire treatments. □ = control, ▨ = first fire, ■ = second fire. Columns associated with the same letter are not significantly different at P<0.05.

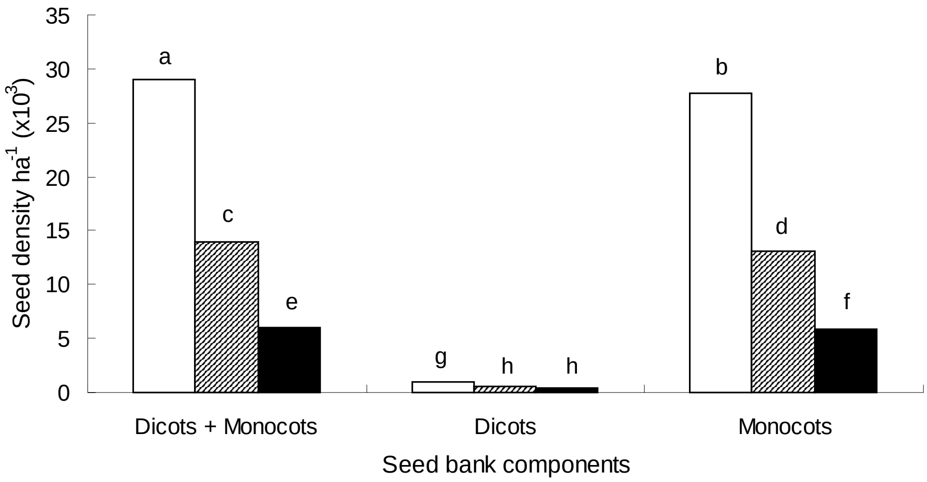

Figure 5. Response of germinable seeds of dicotyledons (dicots) and monocotyledons (monocots) to fire treatments. □ = control, ▨ = first fire, ■ = second fire. Within the same group, columns associated with the same letter are not significantly different at P<0.05.

Discussion

The present study has shown that fire has the ability not only to reduce the density of the population to low levels but also to shift the structure of the population. These are worthwhile changes in terms of integrated management practices and pest-planning management because they make previously expensive management practices such as chemical or mechanical management practices now less expensive to finish the job. The present results also indicate that juvenile rubber vine plants are more susceptible to fire than mature plants which are more susceptible than old plants. This finding is in agreement with findings of Dale (1980).

Weather and fuel characteristics during this experiment interacted to produce a severe fire that achieved a very substantial kill. Results indicate that a single late season fire may kill 80% of rubber vine plants. A follow-up fire a year later may extend the kill rate to 99%. In the study of Dale (1980) where fire was used for four years, the kill rate ranged between 19 and 73%. The discrepancy between our results and those of Dale may be attributed to differences in fire regime and completeness of burn, habitat type, fuel load, physiological condition and different size class distribution of rubber vine. No mention of fuel load was made in Dale's study except that the area (30 km south-west of Charters Towers) was lightly stocked with cattle at one beast per 15 ha. Interestingly the stocking rate at Wrotham Park was much lighter (one beast per 21 ha) than in Dale's experiment. The differences suggest that considerable benefit can result from choosing optimum conditions for fire treatment.

It is likely that the physiological condition and chemistry of rubber vine at the time of the fire may contribute to mortality of rubber vine as well. In our study the rubber vine plants were leafless and appeared drought-stressed at the end of the dry season. Miller *et al.* (1981) reported a higher kill from burning mimosa plants when they were drought-stressed than from burning during dry periods after early wet-season.

Though no conclusive evidence was found in the present study to suggest that fire had any effect on standing pasture biomass, an improvement of pasture quality was achieved. The significant increase in pasture quality after the first fire may be attributed to possible changes in species composition, leaf: stem ratios, carry-over material from season to season, or increases in N mineralization following fire. Pasture quality is still considered very low by Klapp's (1965) 10-fodder value standards. We have recorded a chemical fodder value of one whereas Klapp's 10-fodder value standards extend to a maximum chemical fodder value of eight. The low fodder value may be attributed to the maturity stage, which, in line with work of Partridge and Miller (1991), is typical of tropical grasses in the late dry season. This is also a time when any gains in pasture quality will have greatest benefit.

Although fire diminished the germinable seed bank of both monocotyledons and dicotyledons, the germinable seed bank of monocotyledons appeared to be more susceptible to fire damage than that of dicotyledons. Reductions in the germinable seed bank of both may be attributed to high temperatures recorded at the surface and at 0.5 cm depth. The high range of temperature recorded in this study (675 and 681°C) is not exceptional; other workers (Bradstock *et al.* 1992, Roberts 1965) have reported higher temperatures at similar soil depths. The work of Bradstock *et al.* (1992) with eucalypts has shown that temperatures between 60 and 120°C were lethal for seeds at 0–2 cm depth. Given the large seed bank, some reduction in its size is not likely to have a large impact on post-fire growth. Given adequate moisture, there is still adequate seed of species other than rubber vine to provide good growth after the fire.

Conclusion

Several conclusions can be drawn from the present study. First, a hot fire late in the dry season can kill a high proportion of rubber vine plants; juvenile plants are particularly likely to be killed and a substantial number of mature and old plants are also killed after the first fire. Consequently, a second fire in the next year is well worth using to kill most of the remaining mature plants and reduce old plants to the point where land managers can control what is left using chemical spray or mechanical removal. Second, the rapid regrowth of native pasture species indicates that these species are well adapted to survive fire. They appear to regenerate as seeds, which, though many were killed by a hot fire, still remained in sufficient quantities to provide a diverse and undiminished pasture after fire. Thirdly, fire may increase fodder quality. This benefit is at a time in the year when it is most needed.

More work is needed to assess longer-term impacts on quality and quantity of fodder. With a shift in the seed bank to dicotyledons there could well be a continuing improvement in pasture diversity and standing biomass quality. Finally, it is desirable that there be long-term monitoring of these sites and other similar treatments on other sites, to determine the long-term effects of fire and follow-up management on both rubber vine and the plant community. For example, will grader grass (*Themeda quadrivalvis*) take over or will fire lead to a general improvement of pasture quality and the diversity of native plants. Only such continued monitoring could provide a sound basis for management of rangeland pastures.

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