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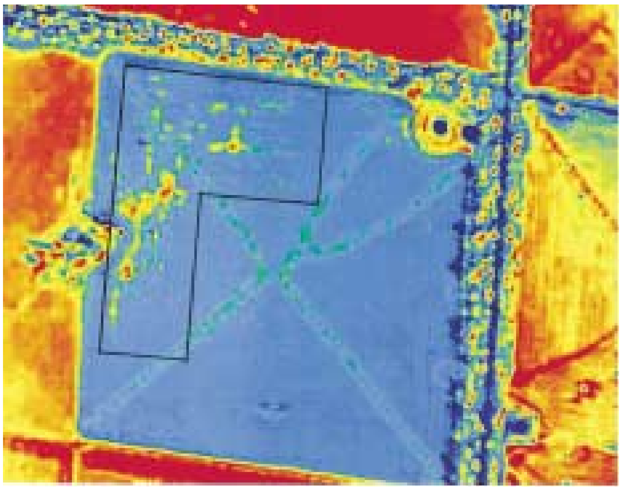

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# Impact of early and late dry-season fires on plant mortality and seed banks within riparian and subriparian infestations of rubber vine (*Cryptostegia grandiflora*)

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*Abstract.* This study compared the efficacy of first and second fires applied during the early (August–September) and late dry season (October–November) on mortality of riparian (climbing) and subriparian (freestanding) infestations of rubber vine (*Cryptostegia grandiflora* R. Br.). The impact of fire treatments on germinable seed banks of monocotyledonous and dicotyledonous species was also determined. Individually, fire season, habitat type and number of fires significantly affected mortality of rubber vine plants. Late-season fires promoted higher mortality of rubber vine (96%) than early season fires (77%), with rubber vine in subriparian habitats more susceptible (90% mortality) than that growing in riparian areas (68% mortality). On average, fire mortality increased from 32% after the first fire up to 86% following 2 fires. Sensitivity of juvenile, mature, and old rubber vine plants to fire was in the order of mature>juvenile>old. Early fires significantly reduced seed banks of monocotyledonous plants, particularly in riparian habitats. Late fires significantly reduced seed banks of both dicotyledonous and monocotyledonous plants. No rubber vine seeds were detected in the germinable seed bank of either burnt or unburnt plots.

## Introduction

The exotic woody weed rubber vine (*Cryptostegia grandiflora* R. Br.) has been classified as a 'weed of national significance' because of its potential to invade most of northern Australia (Mackey 1996). In Queensland, it is already a problem in 87% of shires and cities north of the Tropic of Capricorn (Bebawi *et al.* 2001).

Initial infestations of rubber vine generally occur along rivers and their tributaries, where they smother native vegetation and eventually form dense impenetrable thickets. Subsequent expansion of infestations occurs as it aggressively invades surrounding open woodlands and pastures (Dale 1980). Once established, rubber vine lives for an estimated 80 years, and these plants are capable of producing vast amounts of seed (Eldershaw 2000).

Rubber vine deleteriously affects the livestock industry through reduced yield and quality of forage, interference with grazing, occasional poisoning of animals, increased costs of managing livestock, and reduced land value (McGavin 1969; Chippendale 1991). It has been estimated that rubber vine costs primary industry in Queensland about $18 million per year (Mackey 1996).

Environmental impacts are also substantial as infestation affects wildlife habitat and forage, depletes soil and water resources, and reduces plant and animal diversity (Humphries *et al.* 1991; Tomley 1995).

Numerous control methods have been developed including mechanical and chemical treatments (McFadyen and Harvey 1990), prescribed burning (Grice 1997; Bebawi *et al.* 2000) and biological control (McFadyen and Harvey 1990; Tomley and Hardwick 1996). The most-appropriate method for a given situation (best practice) depends on its cost-effectiveness and the density, size and location of the infestation.

Where rubber vine infestations exceed 2000 plants/ha, the use of fire is considered 'best practice' based on efficacy and economic considerations (Vitelli 1992, 2000). In open woodlands, studies have shown that, if there is sufficient dry fuel (2–9 t dry weight/ha) to produce a fire hot enough to ignite green rubber vine, fire can kill 50–70% of plants (Vitelli 1992). In such instances, the size structure of plants within infestations markedly influences overall efficacy. 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).

Fire regimes vary considerably. Factors such as season, and hence fuel load and moisture, will influence fire duration and intensity. The length of time between periodic fires is also important. Such factors are likely to influence the impact of fire on rubber vine. Preliminary studies have been undertaken of the impacts on rubber vine of 2 fires within 1 year.

Bebawi *et al.* (2000) determined the effect of fire on rubber vine growing in subriparian habitats. They evaluated

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the impact of 2 successive late dry-season fires on mortality of dense freestanding rubber vine. The first fire reduced the rubber vine population by 80% and a second fire, a year later, extended the kill rate to 99%. The relative sensitivity of plants was similar to that reported by Grice (1997), with juvenile>mature>old plants. This study along with one by Dale (1980) indicates that multiple late dry-season fires appear necessary to manage dense rubber vine infestations.

The possibilities of integrated management using combinations of different types of fire have not been explored fully. The usual fire-management practice in the savanna woodlands of North Queensland is to burn extensively in the early dry season, when the country is still relatively moist, and fires tend to be low in intensity, and patchy and small in extent (Andersen 2000*a*). While the impact of late dry-season fires (October–November) on mortality of rubber vine is known, the impact of early fires (August–September) is not understood. The possible impacts of fire regime on desirable species that may replace rubber vine are also not known.

The present study determined the impact of various combinations of fires, 2 early (August–September) and 2 late (October–November) dry-season fires, on mortality of rubber vine infesting riparian (predominantly infested with climbing rubber vine) and subriparian (predominantly infested with freestanding rubber vine) habitats. It also investigated the impacts of fire on the seed bank of other species.

## Materials and methods

### *Site description*

The fire study was undertaken between 1997 and 1999 on a 1-km$^2$ site at Ten Mile Creek (19°58′105″S, 146°29′362″E), 30 km east of Charters Towers, in northern Queensland. It was located within a 1000-ha paddock grazed by cattle at an approximate stocking rate of 1 animal per 6 ha. Throughout the experiment the site remained unfenced, with cattle allowed to graze freely. Burning had not been undertaken for at least 10 years preceding this investigation (Eddy Lavery, Landholder, Ten Mile Creek, pers. comm.).

The climate at the site is strongly seasonal, with almost no rain falling between May and October. The timing of the onset and cessation of the wet season varies between years. Total annual rainfall during 1997 and 1998 was 532 and 1054 mm, respectively, with 82% falling from December to March (Bureau of Meteorology unpublished data). Average monthly maximum temperature in summer is 32°C and an average monthly minimum temperature in winter is 26°C (Bureau of Meteorology, Datadril@bezbox.dnr.qld.gov.au). Scattered frosts occur between June and August; however, these are usually light (Keys 1999).

Bioregionally, the site lies in the Einasleigh Uplands (Broken River Province), which is an essentially hilly province, with shallow soils dominated by narrow-leaved ironbark (*Eucalyptus crebra*) communities (Sattler and Williams 1999). Other native trees in the area included long-fruited bloodwood (*E. dolichocarpa*), red-barked bloodwood (*E. erythrophloia*), broad-leaved ironbark (*E. melanophloia*), white gum (*E. platyphylla*), Moreton Bay ash (*E. tessellaris*), red ash (*Alphitonia excelsa*), river oak (*Casuarina cunninghamiana*), and paper barked teatree (*Melaleuca nervosa*). The shrub stratum was dominated by rubber vine, with currant bush (*Carrissa ovata*) dominating drier parts of the landscape. Buffel grass (*Cenchrus ciliaris*), an introduced pasture grass, dominated the herbaceous vegetation. Native grasses included black spear grass (*Heteropogon contortus*), feathertop wiregrass (*Aristida latifolia*), forest bluegrass (*Bothriochloa bladhii*), pitted bluegrass (*B. decipiens*), Indian couch (*B. pertusa*), and red natal grass (*Melinis repens*). Soils were yellow-grey bleached duplex (Isbell 1996). Soil properties of riparian and subriparian habitats at Ten Mile Creek are given in Table 1.

### *Experimental design*

The experiment included 24 plots, grouped into 12 blocks (30 by 100 m), each containing 2 subplots. For each block, one subplot was randomly located within an area dominated by climbing rubber vine (riparian) and the other in an area of freestanding rubber vine plants (subriparian). Subplots were 36 m$^2$ and contained on average 50 rubber vine plants (14 000 plants/ha).

The 12 blocks were divided into 6 unburnt (control) and 6 burnt, each separated by a 4–10-m wide creek bed, which formed a natural firebreak. Three of the 6 burnt plots were allocated to early dry-season fires (August–September) and the other to late dry-season fires (October–November).

Fire treatments were burnt annually for 2 years. The first late and early dry-season fires were conducted on 6 November 1997 and 21 August 1998, while the second late and early dry-season fires were conducted on 16 October 1999 and 26 August 1999, respectively.

### *Rubber vine measurements*

Before implementation of initial treatments, all live rubber vine plants within plots were marked with numbered pegs and classified into 3 life stages using the methodology of Bebawi *et al.* (2000). This system classifies plants with a stem basal diameter ranging from 0.1 to 2 cm, 2.1 to 30 cm and >30 cm as juvenile, mature and old, respectively. With many rubber vine plants leafless at the time of recording, plants were classified as alive if they exuded latex when struck with a sharp knife at the base of the stem. Percentage foliage cover on a per plot basis was estimated visually for riparian and subriparian populations of rubber vine plants. Plant mortality was recorded the following year before onset of the wet season.

### *Germinable seed bank measurements*

Ten surface soil samples (0–2-cm depth by 314 cm$^2$) were taken from each plot before any rain had fallen on the burnt sites after the fire treatment concerned. Sampling was distributed across each plot to obtain soils representative of the plot. The soil samples were air-dried and bulked. Six subsamples (1 kg each) were taken from this bulked

**Table 1. Soil properties of riparian and subriparian habitats at Ten Mile Creek (Agricultural Chemistry Laboratory Analytical Information Management System, Department of Natural Resources, Indooroopilly, Qld)**

| Soil properties | Habitat | |
|---|---|---|
| | Riparian | Subriparian |
| pH | 8.8 | 7.8 |
| EC (mS/cm) | 0.05 | 0.04 |
| Cl (mg/kg) | 11.6 | 7.1 |
| NO$_3$-N (mg/kg) | 2.2 | 0.7 |
| P (mg/kg) | 5.7 | 5.3 |
| K (meq/100 g) | 0.62 | 0.97 |
| ADMC (%) | 0.41 | 1.67 |
| Coarse sand (%) | 83 | 45 |
| Fine sand (%) | 11 | 25 |
| Silt (%) | 2 | 6 |
| Clay (%) | 3 | 23 |
| Organic C (%) | 0.55 | 0.60 |

sample and placed on perforated plastic pots (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 day and night temperatures of 30 ± 1 and 20 ± 1°C, respectively. Rubber vine, and other dicot and monocot seedlings were counted and removed at 3 fortnightly cycles. The soil was allowed to dry for a week after each cycle, then stirred and watered to field capacity. Seedling emergence was monitored for 2 months until no more seedlings emerged.

### *Fire measurements*

The fuel load and soil moisture content of both riparian and subriparian plots within blocks were estimated on the day of burning. Soil moisture content was determined gravimetrically from 3 randomly selected soil samples (0–5-cm depth) and fuel load was estimated by removing all above-ground plant material from 4 randomly placed 0.5 by 0.5 $m^2$ quadrats. Both the soil moisture and fuel load samples were stored in waterproof plastic bags and transferred to the laboratory where their fresh weights were determined. The samples were then oven-dried (80 and 105°C for 48 h for the fuel load and soil moisture samples, respectively), their dry weight recorded and gravimetric soil moisture and fuel moisture contents calculated. Weather conditions were measured on the day of burning, immediately before ignition of the blocks. Measurements included ambient temperature, relative humidity and wind speed.

Temperatures of fires were measured by placing 5 type-K steel-encased thermocouples on rubber vine crowns, on the ground surface and at 0.5-cm soil depth of riparian and subriparian plots within the experimental site. 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 maximise uniformity in fire behaviour over the site. Drip torches were used to ignite blocks to promote a continuous fire line, with all blocks burnt as head fires following an initial back-burn phase adjacent to the creek.

### *Statistical analyses*

For each variable, statistical analysis of variance was performed to detect differences between treatments. Percentages were arcsin-transformed before statistical analysis and later back-transformed. Evaluation of population sensitivity to fire was detected by use of regression analysis, using the regression coefficient '*b*' in a Finlay and Wilkinson (1963) style analysis, regressing population totals on block totals of all populations. In such an analysis, a regression coefficient value of 1.0 indicates average sensitivity whereas values <1.0 indicate below-average sensitivity and values >1.0 indicate above-average sensitivity. Correlation analysis was also performed on the germinable seed bank of monocotyledonous and dicotyledonous plants in relation to fire season and habitat type.

## Results

### *Fire temperature and duration*

For all fires imposed during the experiment, fuel loads exceeded 3 t/ha (Table 2). During the first-year burns, riparian areas contained more fuel than subriparian areas, but for second-year fires fuel loads in riparian areas were lower than those in subriparian areas. The moisture content of fuel in the first year was lower across all treatments than in the second year, averaging 8 and 16%, respectively. Differences between seasons also occurred with late dry-season fuel 24% drier than early-season fuel. Soil moisture content was low across all treatments and years, averaging less than 2% (Table 2).

Weather conditions experienced during dry-season burns varied between seasons and habitats (Table 2). Ambient temperatures were on average 4°C cooler during early than late dry-season burns. Temperatures also differed between habitat types, with riparian areas 8°C cooler than subriparian areas. A similar trend occurred with humidity, which was, on average, 11% lower in riparian plots. Wind speed was much more constant within riparian areas averaging 2.7 km/h, one-quarter as much than that in the more open subriparian environment.

The weather conditions prevailing during late dry-season burns combined with drier fuel produced hotter fires in both years (Table 3). Temperatures were consistently higher in riparian areas, yet the average duration of increased temperatures was greater in subriparian habitats (Table 3). Temperatures varied markedly within the vertical profile of rubber vine infestations, averaging 902, 416 and 131°C within rubber vine crowns, on the ground surface and 0.5 cm below ground, respectively.

**Table 2. Site conditions during the first and second fire at Ten Mile Creek (Agricultural Chemistry Laboratory Analytical Information Management System, Department of Natural Resources, Indooroopilly, Qld)**

| Variable | No. of burns | Early dry-season fire | | Late dry-season fire | |
|---|---|---|---|---|---|
| | | Riparian | Subriparian | Riparian | Subriparian |
| Fuel load (t/ha) | 1 | 8.2 | 3.4 | 10.2 | 3.8 |
| Fuel load (t/ha) | 2 | 7.0 | 5.3 | 6.8 | 7.4 |
| Fuel moisture (%) | 1 | 8.0 | 14.1 | 5.5 | 5.1 |
| Fuel moisture (%) | 2 | 18.0 | 15.7 | 17.2 | 14.6 |
| Soil moisture (%) | 1 | 1.3 | 0.9 | 1.5 | 1.0 |
| Soil moisture (%) | 2 | 0.7 | 0.9 | 0.8 | 1.0 |
| Ambient temperature (°C) | 1 | 33.0 | 38.0 | 35.0 | 49.0 |
| Ambient temperature (°C) | 2 | 30.0 | 37.0 | 31.0 | 39.0 |
| Relative humidity (%) | 1 | 27.0 | 33.0 | 13.0 | 32.0 |
| Relative humidity (%) | 2 | 25.0 | 30.0 | 14.0 | 27.0 |
| Wind speed (km/h) | 1 | 2.7 | 16.5 | 2.6 | 15.4 |
| Wind speed (km/h) | 2 | 2.9 | 5.8 | 2.7 | 7.7 |

**Table 3. Maximum temperatures and duration of fires at Ten Mile Creek (Agricultural Chemistry Laboratory Analytical Information Management System, Department of Natural Resources, Indooroopilly, Qld)**

Values followed by the same letter within each parameter are not significantly different at $P = 0.05$

| | No. of burns | Early dry-season fire | | Late dry-season fire | |
|---|---|---|---|---|---|
| | | Riparian | Subriparian | Riparian | Subriparian |
| | | *Maximum fire temperature (°C)* | | | |
| Rubber vine crown | 1 | 924a | 693c | 1043a | 814b |
| Rubber vine crown | 2 | 938a | 791c | 1038a | 982a |
| Ground surface | 1 | 366e | 384d | 490b | 573a |
| Ground surface | 2 | 310g | 341f | 420d | 442c |
| 0.5-cm soil depth | 1 | 80f | 110de | 120d | 129c |
| 0.5-cm soil depth | 2 | 103e | 106e | 181b | 226a |
| | | *Duration of fires (min)* | | | |
| | 1 | 13d | 56a | 3h | 16c |
| | 2 | 7f | 10b | 5g | 35b |

*Rubber vine mortality and foliage cover*

Foliage cover of rubber vine plants at the time of burning differed significantly ($P<0.05$) between seasons of burning and the habitats in which plants were growing. During late dry-season fires, foliage cover was 26% greater than during early dry-season fires, averaging 45 and 19%, respectively. Plots in riparian habitats had on average 43% foliage cover compared with 21% foliage for subriparian habitats.

Individually, fire season, habitat type and number of fires significantly ($P<0.05$) affected mortality of rubber vine plants. Late-season fires promoted higher mortality than early season fires (Fig. 1), with rubber vine in subriparian habitats more susceptible than that growing in riparian areas (Fig. 2). On average, fire mortality increased to 90% after a second fire (Fig. 3).

Regression coefficient (‘*b*’) values indicate that the relative response of juvenile, mature, and old plants remained similar, irrespective of the season of burning, habitat and number of burns. Regression coefficients for juvenile, mature and old plants averaged 2.7, 3.0 and 2.4, respectively, indicating that the relative sensitivity to fire was mature >juvenile>old.

*Germinable seed bank*

Late fires significantly reduced the germinable seed bank of both dicotyledonous and monocotyledonous plants in subriparian habitats, on average 87 and 93% when compared with that of the control (Table 4). An early first and second fire significantly reduced the germinable seed bank of monocotyledonous plants, on average 94 and 99%, respectively, in riparian habitats, and 32 and 90%, respectively, in subriparian habitats when compared with that of the control (Table 4). The ratio of germinable monocotyledonous to dicotyledonous plants in riparian and subriparian habitats was about 4:1 and 6:1, respectively. Regression coefficient (‘*b*’) values of germinable seed bank for early and late fires were 1.87 and 1.48, respectively, over all fire and habitat types. Dicotyledonous and monocotyledonous germinable seed bank regression coefficient (‘*b*’) values were 2.82 and 1.03 over all fire seasons, types, and habitats.

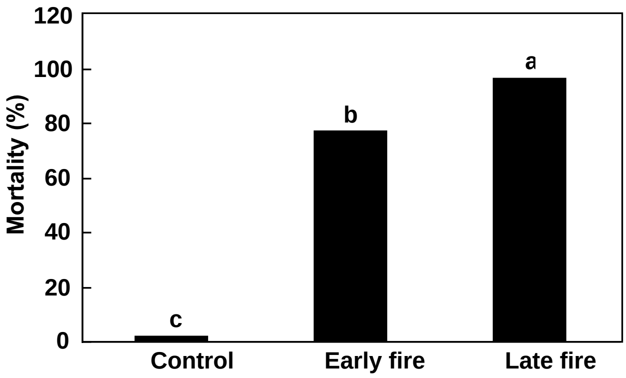

**Figure 1.** Differences in mean mortality of rubber vine between early and late dry-season burns at Ten Mile Creek. Bars with different letters are significantly different at $P = 0.05$.

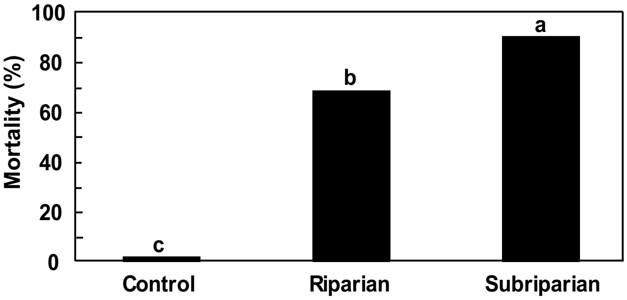

**Figure 2.** Differences in mean fire-induced mortality of rubber vine between habitat types at Ten Mile Creek. Bars with different letters are significantly different at $P = 0.05$.

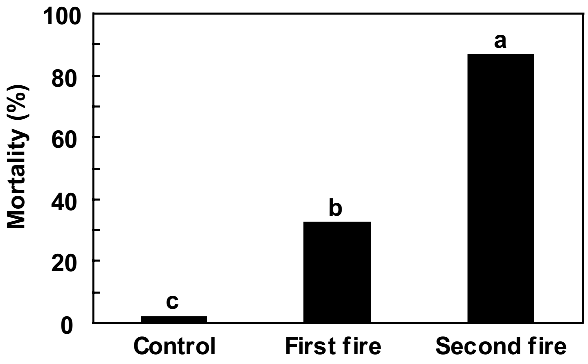

**Figure 3.** The effect of the number of fires on mean mortality of rubber vine at Ten Mile Creek. Bars with different letters are significantly different at $P = 0.05$.

## Discussion

This study yielded 2 key results with regards to dry-season burning for control of riparian and subriparian rubber vine. First, late dry-season fires were more effective than early dry-season fires in reducing the density of rubber vine to low levels. Second, 2 fires are necessary to achieve adequate control. The implications for landholders are far-reaching and in some instances may require significant changes to current practices.

A regime of late dry-season burning will more quickly remove the threat of rubber vine from an area. At least 2 burns will be necessary to ensure a large reduction in the population. Burning at other times in the dry season, such as the commonly practiced early dry-season burning of northern Australia (Andersen 2000*a*), may kill some plants but will generally take longer to reduce populations to a satisfactory level, and, in some instances, may never do so.

Besides dry-season burning, recent research (J. McKenzie unpublished data) has also shown that successful burns to control rubber vine can occur soon after the first rains of the wet season. Burning at this time minimises the period when soil will be bare and at risk of erosion from high-intensity storms (Anderson *et al.* 1988). However, a major short-term limitation is the risk of prolonged rainfall periods occurring, which may promote new pasture growth and consequently reduce the intensity of fires.

Differences in rubber vine mortality between dry seasons could be attributable to several factors, including weather conditions at the time of fire, fuel characteristics and physiological status of plants.

Burning late in the dry season, when conditions are characteristically hot and dry, maximises the chance of fires being of sufficient intensity and duration to kill plants. Fires early in the dry season are generally patchier, particularly in riparian areas, where fuel may not be sufficiently dry to burn (Andersen 2000*b*). Late dry-season fires do, however, require more effort and resources to avoid the risk of wildfires. This is frequently the reason for burning at times of the year when fires are considered easier to control (Grice and Slatter 1997).

An important finding of this study was the higher mortality of rubber vine in subriparian areas than in riparian areas. Maximum temperatures during fires were higher in riparian areas, but the duration of increased temperatures was longer in subriparian habitats. This suggests that the duration of exposure to increased temperatures may be more important in achieving high mortality, rather than the maximum temperature of the fire. Subriparian areas did, however, have less foliage cover and may have been in a more susceptible state. A previous study by Bebawi *et al.* (2000) produced similar findings and led them to conclude that the physiological condition of rubber vine at the time of burning is an important determinant of mortality. In their study, rubber vine plants at the end of the dry season were totally leafless and appeared drought-stressed. Subsequent mortality was 80 and 99%, following first and second fires, respectively. Miller *et al.* (1981) also reported a higher kill from burning mimosa (*Mimosa pigra*) plants when they were drought-stressed than from burning during dry periods after early rain.

The recent introduction of a rust (*Maravalia cryptostegiae*) as a biocontrol agent for rubber vine has seen an additional stress imposed on plants (Mackey 1996). Studies on the effects of this agent suggest that the vigour and reproductive

**Table 4. Germinable seed bank (expressed in million seeds/ha) of monocotyledonous and dicotyledonous plants in riparian and subriparian habitats as affected by a first and second, early and late dry-season fire**

Values followed by the same letter are not significantly different at $P = 0.05$

| Habitat type | Early dry-season fire | | | Late dry-season fire | | |
|---|---|---|---|---|---|---|
| | Control | First fire | Second fire | Control | First fire | Second fire |
| | | | *Monocotyledons* | | | |
| Riparian | 51.58a | 2.97e | 0.44f | 0.85f | 0.11f | 0.99f |
| Subriparian | 7.55c | 5.13d | 0.73f | 12.88b | 2.01ef | 1.42ef |
| | | | *Dicotyledons* | | | |
| Riparian | 1.02ef | 0.67f | 0.35f | 0.41f | 0.15f | 0.20f |
| Subriparian | 0.35f | 0.52f | 1.46ef | 11.95b | 0.79f | 0.84f |

output of plants are markedly reduced (W. Vogler unpublished data). This appears to be improving the efficacy of fires. In the current study, the absence of any viable seeds in the seed bank may be an indication of the effectiveness of the rust. This has significant management implications as the threat of large-scale seedling regrowth following treatment of adult plants has been reduced. Consequently, concerted efforts to control existing infestations are more likely to have long-lasting benefits because the requirement for follow-up action has been reduced.

Before burning in riparian and subriparian habitats, consideration should be given to the native species present and the impact that imposed fire regimes may have on these species. In areas, where there are highly susceptible species, alternative approaches may be needed.

Although both early and late fires reduced the germinable seed bank of both dicotyledonous and monocotyledonous plants in this study, the germinable seed bank of monocotyledons appeared to be most susceptible. Nevertheless, given the large seed bank, some reduction in its size is not likely to have a lasting impact on the plant community.

Although fire can be effective in rubber vine control it is still only 1 of several techniques. Further work is needed to assess integration of methods (fire, chemical, mechanical and biocontrol) to provide even more effective control of rubber vine populations, while causing minimal negative environmental impacts.

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### References

Andersen A (2000*a*) Introduction. In 'Fire and biodiversity, CSIRO's Kapalaga fire experiment, Kakadu National Park, workshop notes'. (Eds A Andersen, BJ McKaige) p. 1. (Biodiversity, CSIRO: Darwin)

Andersen A (2000*b*) Synthesis and management implications. In 'Fire and biodiversity, CSIRO's Kapalaga fire experiment, Kakadu National Park, workshop notes'. (Eds A Andersen, BJ McKaige) p. 13. (Biodiversity, CSIRO: Darwin)

Anderson ER, Pressland AJ, McLennan SR, Clem RL, Rickert KG (1988) The role of fire in native pasture management. In 'Native pastures in Queensland; the resources and their management'. (Eds WH Burrows, JC Scanlan, MT Rutherford) pp. 112–124. (Queensland Department of Primary Industries: Brisbane, Qld)

Bebawi FF, Campbell SD, Lindsay AM, Grice AG (2000) 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. *Plant Protection Quarterly* **15**, 62–66.

Bebawi FF, Campbell SD, Stanley TD (2001) 'Priority list for weed research in North Queensland.' Final Report, Tropical Weeds Research Centre, Queensland Department of Natural Resources, Charters Towers, Qld.

Chippendale JF (1991) 'Potential returns to research on rubber vine (*Cryptostegia grandiflora*) in north Queensland.' MSc (Agric.) Thesis, University of Queensland, Brisbane.

Dale IJ (1980) 'Factors affecting the distribution of rubber vine (*Cryptostegia grandiflora* R.Br.) in north Queensland.' MSc (Agric.) Thesis, University of Queensland, Brisbane.

Eldershaw V (2000) 'Managing rubber vine — an experience based approach to managing a weed of national significance.' Queensland Department of Natural Resources, Brisbane, Australia.

Finlay KW, Wilkinson GN (1963) The analysis of adaptation in a plant-breeding programme. *Australian Journal of Applied Research* **14**, 742–754.

Grice AC (1997) Post-fire regrowth and survival of the invasive tropical shrubs *Cryptostegia grandiflora* and *Ziziphus mauritiana*. *Australian Journal of Ecology* **22**, 49–55.

Grice AC, Slatter SM (1997) 'Fire in the management of northern Australian pastoral lands'. Tropical Grasslands Society of Australia Occasional Publication No. 8. Qld, Australia.

Humphries SE, Groves RH, Mitchell DS (1991) Plant invasion of Australian ecosystems — a status review and management directions. ANPWS, ESP Project No. 58.

Isbell RF (1996) 'The Australian soil classification.' (CSIRO: Australia)

Keys J (1999) 'Draft report on climate and forecasting for Burdekin dry tropics grazing lands strategic plan.' Department of Primary Industries, Charters Towers, Qld.

Mackey AP (1996) 'Rubber vine (*Cryptostegia grandiflora*) in Queensland.' (Queensland Department of Natural Resources: Brisbane)

McFadyen RE, Harvey GJ (1990) Distribution and control of rubber vine, *Cryptostegia grandiflora*, a major weed in northern Queensland. *Plant Protection Quarterly* **5**, 152–125.

McGavin MD (1969) Rubber vine (*Cryptostegia grandiflora*) toxicity for ruminants. *Queensland Journal of Agriculture Animal Science* **26**, 9–19.

Miller IL, Nemestothy L, Pickering SE (1981) '*Mimosa pigra* in the Northern Territory.' Technical Bulletin No. 51, Department of Primary Production Division of Agriculture and Stock, NT, Australia.

Sattler P, Williams R (1999) 'The conservation status of Queensland's bioregional ecosystems.' (Environmental Protection Agency: Brisbane, Queensland)

Tomley AJ (1995) The biology of Australian weeds 26. *Cryptostegia grandiflora* R.Br. *Plant Protection Quarterly* **10**, 122–130.

Tomley AJ, Hardwick G (1996) Bulking up, field distribution and establishment of rubber vine rust, *Maravalia cryptostegiae* in far north Queensland. In 'Proceedings of the 11th Australian weeds conference'. (Ed. RC Shepherd) pp. 237–238. (Weed Science Society of Victoria: Melbourne)

Vitelli JS (1992) Fire. In 'The control and management of rubber vine'. (Ed. B Shepherd) p. 15. (Queensland Department of Primary Industries: Brisbane, Qld)

Vitelli JS (2000) Options for effective weed management. In 'Proceedings of pastures for production and protection'. Tropical grassland conference 2000, Emerald, Qld, 26–28 April 2000. pp. 104–113. (Tropical Grassland Society of Australia)

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