Responses of two species of mesquite to initial and follow-up applications of selected herbicides in a potted trial

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Abstract

Quilpie mesquite (*Prosopis velutina*) is an invasive woody weed that is believed to have been introduced into south-west Queensland in the 1930s. Following the withdrawal of 2,4,5-T, research on *P. pallida* resulted in revised recommendations for control of all *Prosopis* spp. in Queensland. Adoption of many of these recommendations for Quilpie mesquite control produced substandard results. Following a pilot trial, a shade-house experiment was conducted to determine the differences in susceptibility of two species of mesquite, *P. velutina* and *P. pallida*, to commonly available herbicides. It was hypothesized that *P. velutina* was less susceptible than *P. pallida*, based upon claims that the registered chemical recommendations for *Prosopis* spp. were not sufficiently effective on *P. velutina*.

Nine foliar herbicide treatments were applied to potted shade-house plants. Treatment effects indicated differing susceptibility between the two species. *P. velutina* consistently showed less response to metsulfuron, fluroxypyr, 2,4-D/picloram and triclopyr/picloram, compared to the glyphosate formulations, where negligible differences occurred between the two species. The response to glyphosate was poor at all rates in this experiment. Re-application of herbicides to surviving plants indicated that susceptibility can decrease when follow-up application is in autumn and the time since initial application is short.

The relationship between leaf structure and the volume of spray adhering to a plant was assessed across species. The herbicide captured by similar-sized plants of each species differed, with *P. pallida* retaining a greater volume of herbicide.

Introduction

Prosopis (mesquite) has been spread around the world as a beneficial plant group since the early 1800s. There have been many large scale, co-ordinated introductions into arid regions of the world, as well as innumerable *ad hoc* introductions (Felker and Moss 1996). The potential benefits for Australia of several *Prosopis* species were promoted to the Victorian State Parliament by 1871 (von Mueller 1876). There have undoubtedly been multiple introductions of mesquite into Australia, mostly for shade, browse and perceived habitat improvement.

The four naturalized invasive *Prosopis* species, (*P. glandulosa* Torrey var. *glandulosa*, *P. pallida* (Willd.) H.B.K., *P. velutina* (Woot. (syn. *P. flexuosa* DC.)) and *P. juliflora* ((Sw.) DC.) in Australia all originate from semi-arid South America (Burkart 1976). Quilpie mesquite (*Prosopis velutina*) is an invasive prickly woody weed that was believed to have been introduced into south-west Queensland in the 1930s (Parsons and Cuthbertson 1992). Although it produces palatable pods and provides some shade for grazing stock, it develops dense thickets, which reduce pasture growth. Mesquite species are declared in Queensland under Schedule 2 as Class 1 pest plants (to be excluded or eradicated) except for *P. glandulosa*, *P. pallida* and *P. velutina*, which are Class 2, already recorded in Queensland (under the Land Protection (Pest and Stock Route Management) Regulation 2003). Landholders must take steps to keep properties free of Class 2 pest plants. *Prosopis* species have a similar status in other Australian states, with even Tasmania prohibiting seed.

The principal control method for *Prosopis* spp. is chemical. Following the withdrawal of 2,4,5-T, research on *P. pallida* resulted in revised recommendations for control of all *Prosopis* spp. in Queensland. Control failures have been reported when herbicide recommendations commonly effective in north Queensland for controlling *P. pallida* were applied to *P. velutina* in south-western Queensland. Due to the adoption of generic extension guidelines on woody weed control, the differentiation between species' responses to herbicides was not formally recognized or recorded. Furthermore, the relative isolation and restricted distribution of *P. velutina* in Queensland contributed to the adoption of generic herbicide recommendations.

We report on two replicated experiments designed to determine the susceptibility of young *P. velutina* and *P. pallida* plants to some commonly available herbicides. The second experiment looked at susceptibility of regrowth to further herbicide treatment. Branch size and leaf area were studied to determine herbicide spray volume retained for each species and to establish whether a relationship existed between volume retained on leaf surfaces and susceptibility to herbicides.

Materials and methods

Two experiments were conducted in a shade-house at the Alan Fletcher Research Station, Sherwood, Queensland. Plants of each species were grown in 12.5 cm diameter pots. The foliage had been pruned once during the previous summer to economize on space and irrigation requirements. The plants were 7.5 months old when spraying commenced.

First treatment

In the first experiment spraying was undertaken on April 18, 1999, and plants were assessed 12 times over six months in order to incorporate periods of quiescence during winter and re-shooting in the spring. Application techniques used 60 L plastic bins to contain spray and were adapted from Black *et al.* (1998), who used the Australian Weeds Committee ranking assessment system (Australian Weeds Committee 1979) and the bin confinement to deduce a herbicide effect. Refinements to the process were developed in a pilot trial (Sparkes and Panetta 1999).

Experience in field assessment and the realization that potted plants could be more susceptible to standard field herbicide dosages gave some indication of treatment rates. Treatments were grouped into either high (normal label registered rate) or a lower dosage rate modified from rates that had shown activity in the pilot trial (Sparkes and Panetta 1999), in conjunction with field observations on *P. pallida* in north Queensland (Table 1). One dose of the 2,4-D + picloram mixture was included in this experiment to determine if activity existed as an aid for future research. Foliage of 600 plants was sprayed to runoff. There were 10 *P. velutina* and 10 *P. pallida* tagged plants within each treatment block. Plants for each treatment were randomly arranged in three blocks of 20 to account for different shade-house aspects after being randomly selected from a larger group of potted plants. Thirty plants of each species (10 in each block) constituted the control groups. Plants within each group were sprayed with one treatment. Plant height, the number of branches, and the number of leaf petioles were measured and recorded at the time of spraying.

For this first experiment herbicide responses were assessed weekly when

Table 1. Herbicides applied to mesquite species.

Treatment	Manufacturer	Trade name	Active constituent	Product dilution (a.i. g 100 L^{-1})
1.	Dow	Grazon* DS	300 g L^{-1} Triclopyr (present as the butoxyethyl)	54
			100 g L^{-1} Picloram (present as the exyloxypropylamine salt)	18
2.	Dow	Grazon* DS	300 g L^{-1} Triclopyr (present as the butoxyethyl)	105*
			100 g L^{-1} Picloram (present as the hexyloxypropylamine salt)	35*
3.	Dow	Tordon* 75-D	300 g L^{-1} (2,4-D present as the tri-isopropanolamine salt)	90*
			75 g L^{-1} (Picloram present as the tri-isopropanolamine salt)	22.5*
4.	DuPont	Brush-off	600 g kg^{-1} Metsulfuron methyl	3
5.	DuPont	Brush-off	600 g kg^{-1} Metsulfuron methyl	6
6.	Dow	Starane*	300 g L^{-1} Fluroxypyr as methylheptyl ester	60
7.	Dow	Starane*	300 g L^{-1} Fluroxypyr as methylheptyl ester	150*
8.	Monsanto	Roundup	360 g L^{-1} Glyphosate (present as isopropylamine salt)	180
9.	Monsanto	Roundup	360 g L^{-1} Glyphosate (present as isopropylamine salt)	360*
10.	Control	–	–	–

* indicates normal label strength.

herbicide-induced deterioration was most marked, and then fortnightly throughout winter over a six month period. Deterioration was assessed (using a ranked scale from 1–7, 1 being the most severely affected (Figure 1)) on 12 occasions, commencing on the spray date 19 April 1999 (assessment 1), 12 May (2), 27 May (3), 23 June (4), 15 July (5), 29 July (6), 13 August (7), 6 September (8), 20 September (9), 5 October (10), 22 October (11), with the last assessment (12) being 4 November 1999 (Figure 1).

Re-treated plants

The trial on re-growth susceptibility commenced following spraying in early February, 2000 with six equally spaced assessments. The second experiment measured susceptibility to a follow up spray. Following the first spray treatment, the potted mesquite plants that survived were rejuvenated by pruning dead tissue and applying frequent low dosages of a liquid-fertilizer for four months. Herbicides were re-applied to these plants together with freshly grown plants (Figure 3 and Table 1), in order to evaluate susceptibility of species to re-treatment with the same herbicide mixture in summer growing conditions. In this experiment 300 new plants of each species were incorporated in addition to the previous 60 control plants, from the first experiment, to achieve a balanced experimental design. These plants were assessed against 363 rejuvenated plants surviving from the initial experiment; thus a minimum of 60 unsprayed plants, comprising three blocks for each species × treatment combination, were used as the single application reference group. The exception, since plant numbers were decreased for some previously sprayed groups, was triclopyr + picloram, where replication was reduced. The trial plan included dosage rates that were the same as for the earlier application.

The response to re-treatment was assessed six times from 10 March 2000 (assessment 1), 16 March (2), 31 March (3), 17 April (4), 5 May (5) to a final assessment (6) on 18 May 2000 (Figure 3).

Estimation of plant size

Plant size was determined by calculating a branch size ratio equating to the number of branches over 30 cm in length relative to total branch number. The branch ratio was converted into a categorical variable, with a ratio less than 0.334 equalling 1, 0.334 to less than 0.667 equalling 2, and greater than 0.666 equalling 3.

Adherence of spray to leaves

The relationship between leaf structure and the volume of spray adhering to a plant was assessed across species. *P. velutina* has a compound leaf comprising, on average, two pinnae connected directly to a combined rachis-petiole structure. *P. pallida* has four to six shorter pinnae per compound leaf. A random selection of 100 leaf structures from each species was examined and measured under a stereoscopic microscope to determine comparative adherence areas.

The spray volume adhering to leaves and pinnae was calculated as per the initial pilot trial (Sparkes and Panetta 1999). Linear regression was used to determine a relationship between plant morphological features (i.e. leaflet size and number) and spray dosage adhering to plants. In the preliminary analysis, correlation analysis between volume adhering to individual mesquite plants and morphological features was conducted using partial residual coefficients in order to determine which factors were important in determining spray adhesion to plant tissue for each species.

Analysis

Results from the herbicide response experiments were analysed using Systat 9 (Wilkinson 1998), with a repeat measure multivariate analysis of variance approach, as used for assessing herbicide susceptibility (Sparkes and Panetta 1997). A graphical presentation differentiates between the treatment and species response effects (Figure 1). In the graphical presentation data points were averaged for each assessment time × treatment and distance-weighted least squares smoothing applied. A multivariate repeat measure analysis was carried out with two between-subject variables in the form of herbicide treatment and block (based on position within the shadehouse), and seven within-subject variables in the form of the seven assessment ratings (1 = dead to 7 = normal growth tissue) over the 12 assessment times. The ratings provided a descriptive sequential numerical coding that reflected the dominant characteristics of herbicide symptoms whilst also reflecting control plant characteristics (Figure 1). Post-hoc herbicide treatment and random positioning effects were moderated using Bonferroni adjustment (Wilkinson and Coward 1994).

Results

First treatment

Metsulfuron (treatments 4 and 5), fluroxypyr (treatments 6 and 7), 2,4-D + picloram (treatment 3), and triclopyr + picloram (treatments 1 and 2) showed the most pronounced differences between species' susceptibility, with *P. pallida* being 44% more susceptible compared to *P. velutina* (Figures 1 and 2).

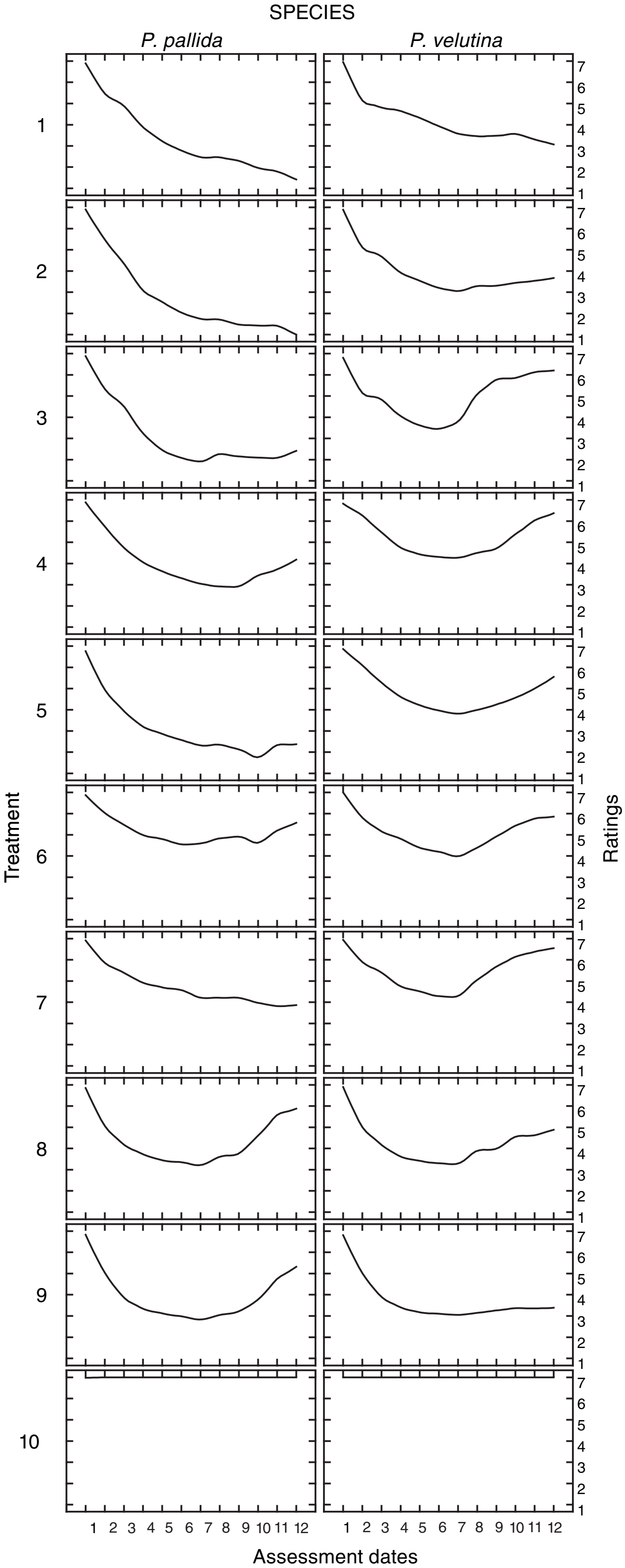

Figure 1. Response of two species of *Prosopis* to nine herbicide formulations and a control during the autumn to spring period 1999. Treatment (1) triclopyr/ picloram low conc. (2) triclopyr/picloram high conc. (3) 2,4-D/picloram triclopyr (4) metsulfuron low conc. (5) metsulfuron high conc. (6) fluroxypyr low conc. (7) fluroxypyr high conc. (8) glyphosate low conc. (9) glyphosate high conc. (10) control. Rating assessments are 7 = no damage, 6 = leaves yellowing/necrotic, 5 = leaf death, 4 = stem death <20 cm, 3 = stem death >20 cm, 2 = total stem death, 1 = death of whole plant. (Stem death measured from meristematic tip). Assessment dates are provided in the Materials and methods section.

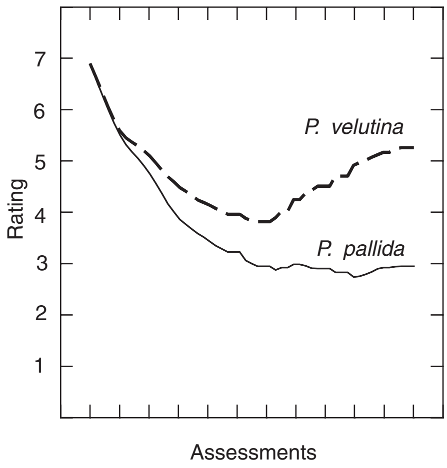

Figure 2. Mean treatment response (all herbicide treatments) indicating that species reaction to herbicide application is divergent. Rating assessments are as in Figure 1. The first assessment on April 18, 1998 was followed by 11 assessments at two week intervals.

There was a difference in treatment effect, with higher concentrations of herbicide producing significantly more damage over the 12 assessments (F (1, 559) = 14.31 P <0.01). *P. pallida* was susceptible to a wider range of herbicides, particularly at higher concentrations (Figures 1 and 3). The between-subjects categorical variables herbicide treatment (F (9, 601) = 181.05, P <0.01) and species (F (1, 601) = 228.77, P <0.01) were significant in their effect on assessment scores (Figure 1 and Table 1). The blocking effect was not significant (F (2, 558) = 0.35, P = 0.7), indicating uniform exposure to background parameters such as shading, watering and fertilizer regime. Assessments 1 and 2 indicated that the two species of mesquite responded similarly to the treatments. The effect of species difference in response was first apparent between the 3rd and 5th assessments (Figures 1 and 2). The high strength triclopyr/ picloram treatment (2) was significantly more effective than the higher strength metsulfuron methyl treatment (5) for both species. Treatments 2 and 5 were 73% and 57% more effective, respectively, on *P. pallida* when compared to the responses of *P. velutina*. When considering *P. velutina*, the high strength triclopyr + picloram formulation (treatment 2) was significantly more efficacious than treatment 5, the higher strength metsulfuron methyl treatment (F (1, 300) = 30.29, P <0.01), with a 34% difference compared to the lower more uniform response for *P. pallida* (F (1, 300) = 5.8, P <0.05), where there was a 58% difference. This trend of higher efficacy for triclopyr + picloram was repeated when comparing

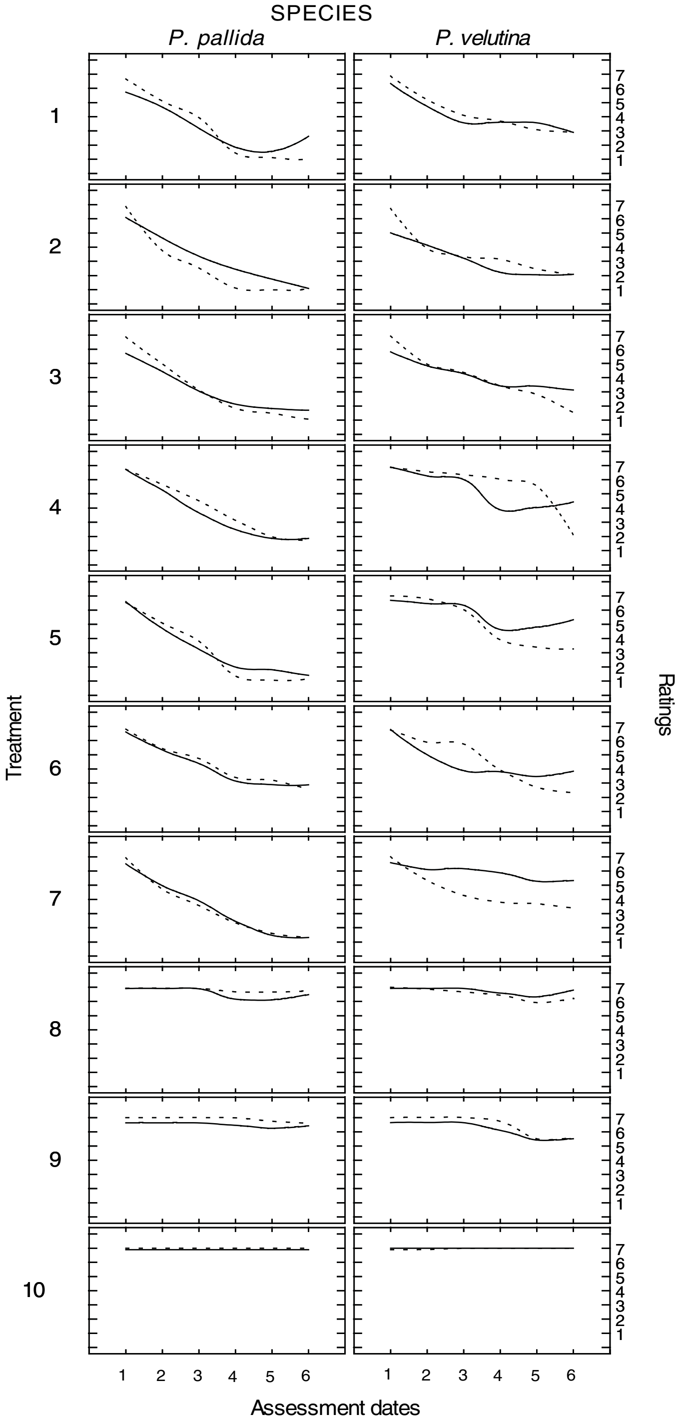

Figure 3. Treatment response of two species of *Prosopis*, incorporating previously unsprayed and retreated plants, to nine herbicides and a control all treated in late summer. Line differences indicate previously unsprayed plants (dotted line); retreated plants (solid line). Treatment (1) triclopyr/picloram low conc. (2) triclopyr/picloram high conc. (3) 2,4-D/picloram triclopyr (4) metsulfuron low conc. (5) metsulfuron high conc. (6) fluroxypyr low conc. (7) fluroxypyr high conc. (8) glyphosate low conc. (9) glyphosate high conc. (10) control. Rating assessments are as in Figure 1.

treatment 2 with the lower strength metsulfuron methyl treatment (4), although *P. pallida* was much more susceptible to the lower strength metsulfuron methyl in this potted trial. A similar trend of differing susceptibility was followed in comparing triclopyr + picloram and the lower and higher strength fluroxypyr treatments 6 and 7. Both dilution rates of glyphosate, treatments 8 and 9, although globally significant in response relative to the control plants, showed re-shooting and healthy recovery from the 8th assessment (Figure 1). All treatments were significantly different from the controls (*F* (9, 611) = 103.59, P <0.01) (Figure 1).

Re-treatment

As in the first application, the effects of the between-subject variables, treatment and species, were all highly significant, with *P. velutina* less susceptible compared to *P. pallida* (Figure 3). There was a significant difference between the responses in general (Figure 3). This occurred in spite of the buffering effect of the glyphosate response, where there was no difference between newly sprayed plants and re-sprayed plants (treatments 8 and 9 in Figure 3). The lower dosage triclopyr + picloram treatments caused a similar response to that of glyphosate when comparing newly sprayed and re-sprayed plants. However, at the higher rate of triclopyr + picloram there was a difference (Figure 3), but significantly so only towards the 4th and 5th assessments (*F* (1, 419) = 1.59, P = 0.02), with a 72% difference in species response and a 70% difference between the 5th and 6th (*F* (1, 419) = 4.81, P = 0.02) assessments. However, responses to specific treatments showed that differences also occurred soon after application. The 2,4-D + picloram treatment had a more destructive effect initially on the retreated plants (*F* (1, 419) = 4.45, P = 0.03) but, overall, over the long term the previously untreated plants tended to be the most susceptible (*F* (1, 419) =3.08, P = 0.08). Importantly, there was a species-dependent difference in response, with previously treated *P. velutina* being less susceptible to re-treatment.

The low concentration of metsulfuron methyl, which normally has little effect on *P. velutina,* caused differentiation in response towards the later assessments, with retreated older plants being severely affected between the 3rd and 4th assessments (*F* (1, 419) = 116.73, P <0.01), giving a 43% reduction in vigour compared to controls. Previously unsprayed plants were slower to respond but did suffer more pronounced damage between the 5th and 6th assessment (*F* (1, 419) = 7.93, P <0.01, with a 64% loss in vigour compared to controls).

The higher concentration of metsulfuron methyl again showed previously unsprayed *P. velutina* to be more susceptible towards the end of the assessment period, with a 42% difference in response compared to re-treated plants (Figure 3). The higher concentration of fluroxypyr (treatment 7) caused newly sprayed plants of *P. velutina* to be more severely affected at the assessment times towards the conclusion of the experiment (Wilks Lambda = 0.83, *F* (5, 415) = 16.9, P <0.01), with 57% greater deterioration than the control group. Both previously unsprayed plants and re-treated plants of *P. pallida* were more readily killed by higher concentrations of fluroxypyr, compared to *P. velutina*. The lower dose of fluroxypyr produced relatively poor responses in *P. velutina*, although previously unsprayed plants exhibited 66% deterioration compared to the control. *P. pallida* showed high susceptibility (approximately 58% difference from the control) but no difference between previously unsprayed and re-treated plants.

Both dosages of fluroxypyr produced sub-lethal effects in *P. velutina*, in line with results from an earlier pilot trial (Sparkes and Panetta 1999).

Adherence of spray to leaves

There was no correlation between plant height, number of branches, and an averaged ranked score determined across all assessment times using partial correlation coefficients (results not presented). There was a marginal relationship between plant height, number of branches and net spray adhering to plants. In contrast, when analysis was completed, species and branch ratio crossed with treatment showed that significant differences did occur in the ratings of treated mesquite.

The simplest model to predict adherence of spray could be achieved by using the branch ratio alone. Thus, in young pruned *P. velutina* plants, the predictive model was $y = -14.067 + 47.578x$, where y = net spray adhering to plants and x = branch ratio, while it was $y = -13.74 + 47.809x$ for *P. pallida*, with 25% more spray adhering to *P. pallida* (F (1, 549) = 8.864, $P < 0.01$), compared to *P. velutina* at the same age. This was a consequence relating to the age and condition of plants in that spray adhesion correlation with smaller branches became weaker as plants grew larger. It appeared that susceptibility to a dosage of herbicide for larger plants was more strongly correlated with leaf area and number of branches over 30 cm in length. The number of petioles was a weaker predictor of adhered spray, because of the leaflet size difference between the two species, with *P. velutina* having both larger leaflet size and larger petioles. The number of petioles was significantly different between species, with *P. velutina* having on average less that half the number of *P. pallida*.

The length of the leaflets (difference = 2.9 ± 1.48 mm, df = 1, 19, $P < 0.01$; compared by t test) and the length of the pinnae (difference = 14.85 ± 3.18 mm, df = 1, 19, $P < 0.01$) of *P. pallida* can be noticeably less than those of *P. velutina* when grown under the same conditions. This indicates that a larger surface area per leaf that would appear to be available for herbicide capture in *P. pallida*, given the higher number of pinnae per compound leaf, is somewhat negated by the smaller morphology of its leaflets and pinnae.

The herbicide captured by similar sized plants of the two species differed (difference = 3.39 ± 1.17 mL, t = 7.038, $P < 0.01$). *P. pallida* retained a greater volume of herbicide (13.75 mL per plant) compared to that of *P. velutina* (10.36 mL per plant).

Using all data from both species, there was a correlation between the volume of spray adhering to each mesquite plant, and the ratio of number of branches over 30 cm in length to total branch count (branch ratio) and, to a lesser extent, with the number of petioles.

Discussion

In general, mesquite response to the herbicides reflected outcomes that had been observed in field operations. The results can be confidently reproduced under most varied field applications.

First treatment

The differences in treatment response, with *P. pallida* being more susceptible to some herbicides than *P. velutina*, confirm the findings of a previous pilot trial (Sparkes and Panetta 1999) and reflect reports from field applications in both north and south-west Queensland. Metsulfuron methyl, triclopyr + picloram, fluroxypyr, then 2,4-D + picloram produced more effective results in *P. pallida*. The herbicide response trends produced in the pilot trial (Sparkes and Panetta 1999) for many treatments were also confirmed in this study. As multiple rates of each herbicide were applied, a correlation trend associated with herbicide dosage was able to be developed and indicated that higher strength produced improved efficacy for all herbicides except glyphosate (Figure 3). The high variance associated with some responses in the pilot trial (Sparkes and Panetta 1999) was reduced in this trial because of the large number of mesquite plants examined.

However, the lack of a reliable response by *P. velutina* to some treatments observed in this shade-house trial is consistent with similar results obtained in the field in south-west Queensland. The response of *P. velutina* to some treatments is apparently conditioned by the environment. This particularly applies to glyphosate and the triclopyr + picloram formulations, where seasonal rainfall around Quilpie is thought to be the determining factor (Sparkes and Midmore 2004). These observations indicate a need to monitor some registered rates for *P. velutina* control if application is to occur in dry summers. The relative ineffectiveness of these herbicides in trials conducted in early and late summer is in contrast to their general effectiveness in autumn application (Sparkes and Midmore 2005) in Quilpie Shire.

In a field situation *P. pallida*, being a much more erect species, is treated by basal stem application of oil-based formulations and burning. Significant monsoonal rain, prior to treatment, triggers active growth that is necessary for effective herbicide response as long as this is outside the podding window. High susceptibility of field treated *P. velutina* to triclopyr + picloram, 2,4-D + picloram, and glyphosate is dependent upon high soil moisture levels and rainfall immediately prior to spraying (Sparkes and Midmore 2004), but without significant rainfall within three weeks post spraying, particularly where water ponding adjacent to *P. velutina* is probable.

This trial provided evidence that *P. pallida* was more susceptible than *P. velutina* to metsulfuron, fluroxypyr, 2,4-D + picloram, and triclopyr/picloram treatments (Figure 1). When compared to the most effective treatment, responses to these herbicides did not display the same linear trend in the rate of deterioration of treated plants. The lower dosages of metsulfuron and fluroxypyr were slower to induce a response compared to the lower dosage of triclopyr + picloram, even in *P. pallida* (Figure 1).

Mesquite response to the herbicides may have been enhanced due to the funnel channelling effect of the pot perimeter. However, as the influence was consistent for all applications and species it is suggested the effect did not compromise the outcome.

In this study metsulfuron methyl proved ineffective against *P. velutina*. Similar results were obtained in the USA, where chlorsulfuron and metsulfuron-methyl were effective on the woody shrub Texas whitebrush (*Aloysia gratissima*), killing 70–75% of the plants at 0.28 kg ha^{-1} but ineffective on honey mesquite (*P. glandulosa*), killing no more than 10% of the plants at 1.12 kg ha^{-1} (Meyer and Bovey 1990). Similar field responses have been observed at the low dosage (Table 1). The lack of effect could be a result of damage to metabolic pathways so that the active component is inhibited from disrupting cell growth (Vila-Aiub and Ghersa 2005).

Fluroxypyr was not effective in controlling *P. velutina*. There was less than 10% plant mortality, with most plants showing only leaf damage. In trials conducted by MacDonald *et al.* (1994) on the susceptibility of different species to fluroxypyr, more fluroxypyr was recovered in the susceptible species (70%) than in tolerant species (30%), 120 hours after application. Selectivity differences between the tolerant and susceptible species may be the result of enhanced metabolic transformation of the herbicide to more polar, non-phytotoxic compounds with limited mobility within the tolerant species (MacDonald *et al.* 1994).

There was only a marginal difference in treatment response between the last two assessments for both species (F (9, 601) = 2.38, $P < 0.05$) due to the herbicide effect being maximized earlier and partial recovery continuing in plants that received a sub-lethal dose.

Re-treated plants

Re-application of herbicides occurred in late summer. Following the final assessment it could be seen that *P. pallida* plants, whether re-sprayed or not, were equally susceptible to the applied treatments when compared to the initial application (Figure 3). Glyphosate produced low efficacy, presumably due to poor translocation of herbicide to the root system in early March when the weather was still consistently hot. Indeed, glyphosate response in *P. pallida* was not significantly different from the control (Figure 3). The higher rate of the triclopyr/picloram formulations (treatment 2) produced accelerated deterioration in many newly sprayed plants compared to the re-sprayed plants. However, significance was not achieved through the course of the assessments (F (5, 415) = 2.408, P = 0.07), because of the high variance and low re-sprayed plant numbers in the sample. Specifically, the re-spraying of *P. velutina* produced results with high variance within the sample blocks. The enhanced susceptibility in newly sprayed plants of *P. velutina* (at the final assessment) to both metsulfuron and fluroxypyr was inconsistent with results produced when plants were sprayed on April 18 and could be explained by the lushness of the foliage in these container grown plants at the time of application, as they were propagated in shade-house conditions. Again, a differentiation between the first treatment and the re-treatment trial owing to season of application was in evidence. This has been noted in the field, along with the high variance in treatment response (Sparkes 2003).

In the pilot study, summed branch length and plant height were correlated to the amount of herbicide adhering to plants (Sparkes and Panetta 1999). However, analysis of data in this larger pot trial indicated that the importance of independent variable predictive coefficients had changed compared to the pilot trial as a result of pruning in the latter trial. The predictive coefficient now related to green tissue surface area. This was a consequence of the need to keep the biomass of the plants at an optimum level for the space allocated for the larger experiment and flow on effects such as watering maintenance.

Mesquite growing in the field can respond differently as a consequence of seasonal timing of spray application, poor within-season conditions, or unpredicted rainfall. As can be seen from this study, variance in response to treatment applications can also occur as a result of previous damage. In the field mesquite may be at less than its full growing potential and metabolic pathways may not fully react to applied herbicide, producing variability in response. This variability can lead to the production of higher than normal incidence of re-growth or sub-lethal plant damage. The re-application of herbicides to susceptible species has to be a managed process. Often poor advice is given and inappropriate pressure is put on operators to clean up 're-growth' following an initial control process. Herbicides act on metabolic pathways to achieve efficacy (Grossmann 2005). Until plants are in a condition that can fully metabolize the re-applied herbicide, resources can be wasted and non-target species can be subjected to needless herbicide exposure (Goldwasser *et al.* 2001).

The poor response of potted mesquite to glyphosate applied in late summer differed from observations of high efficacy noted in the field with autumn application (Sparkes 2003). It has been shown, particularly in relation to aerial spraying (Sparkes and Midmore 2004), that for optimal glyphosate response the dose has to be increased to 1:100 for the 450 g a.i. formulation which has no added wetters. The water carrier should be acidified. The addition of propionic acid + soyal phospholipids to the tank formulation also improved efficacy. Extensive glyphosis can inhibit mesquite growth for up to two years.

The root systems of potted plants do not reflect the prolific volume of root tissue that exists in field-grown mesquite. It could be argued that the potted mesquite plants were in a constant state of summer growth, with the root system trying to escape the bounds of the pot.

Recommendations with implications for registered labels

The adoption of generic, non-species-specific herbicide recommendations for mesquite species should be considered with caution. The label instructions for Grazon*DS are for treatment at 1:285 (350 mL 100 L^{-1}) in water + non-ionic wetters at 1:1000 for all *Prosopis* spp. These instructions seem appropriate to *P. velutina* only when applied as overall foliar spray when the soil moisture is high and immediately following a rain event. The addition of extra wetter can improve herbicide response.

More definitive recommendations with adequate qualification need to be presented on pesticide labels. Previous problems associated with global generic recommendations (such as an unacceptable increase in number of applications to achieve control), and the associated extra expense and environmental contamination, should be addressed by research to refine species-specific herbicide efficacy.

Metsulfuron and fluroxypyr have not been incorporated into treatments for *P. velutina* in the field to date as a result of these experiments. Glyphosate has found a niche for controlling seedlings up to one year old and stunts growth and prevents flowering for up to two growing seasons.

Triclopyr butoxyethyl ester 300 + picloram hexyloxypropylamine 100 is registered throughout Australia at 105 g and 35 g 100 L^{-1}. However, field proofing of this experimental data has resulted in 201 g and 67 g 100 L^{-1} being registered for Queensland where the less susceptible *P. velutina* grows in the south-west.

Conclusions

Results from these trials indicate that *P. pallida* and *P. velutina* respond differently to applied herbicides and that *P. pallida* is more susceptible. Re-application of herbicides to previously damaged plants of *P. velutina* and, to a lesser extent *P. pallida*, has to be conducted at a time when metabolic pathways have recovered enough to metabolize the active ingredient of re-treatments. The outcome also points to the need to err on the side of caution when seeking full label registration based on the diversity that exists within the mesquite genus. A more conservative approach may involve obtaining an approved permit covering specific geographical areas so that up-to-date information is disseminated to applicable localities.

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Suppression of germination and establishment of native annual rice by introduced para grass on an Australian monsoonal floodplain

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Summary

The native annual wild rice (*Oryza meridionalis*) underpins the vertebrate food chain on the monsoonal floodplains of northern Australia. It is being displaced by the exotic perennial para grass (*Urochloa mutica*). This study reports on a field experiment, where wild rice seed was sown into 1 m² quadrats of established para grass. Para grass cover was manipulated above the wild rice seed bed, including clipping and herbicide application. The behaviour of wild rice seed under para grass cover in this study was then compared to its behaviour under wild rice cover in a previous study.

***Oryza meridionalis* plants did not establish under para grass treatments, including herbicide treatments that successfully killed para grass. Retrieval of buried bags of wild rice seeds revealed that germination was suppressed. Although 40% of seeds remained viable in the soil for more than 2.5 years, suppressed germination prevented establishment of *O. meridionalis* populations. Under wild rice cover most seed germinated by this time.**

High biomass and complex architecture of para grass cover may modify the seedbed, preventing wild rice seeds receiving dormancy-breaking or germination cues. Simply spraying established para grass with herbicide may not allow re-establishment of wild rice. Additional site treatments may be required for re-establishment by *O. meridionalis* in wetlands managed for biodiversity.

Keywords: *Oryza meridionalis*, biomass, seed-bank, germination, dormancy, invasive grass, monsoonal wetlands.

Introduction

There is a pressing need for information on the ecology of floodplain species and their use in the management and rehabilitation of areas affected by exotic species. Given the limited resources to manage the extensive monsoonal floodplains in northern Australia, it is critical to focus resources on effective management actions that will promote native species with high conservation value (Byers *et al.* 2001).

Oryza meridionalis Ng (wild rice) is an ecologically important annual native wetland grass on the monsoonal floodplains of northern Australia. *O. meridionalis* seed production underpins the vertebrate food-chain at a critical time during the annual floodplain wetting and drying cycle. Magpie geese (*Anseranas semipalmata*) rely on the abundant *O. meridionalis* seed in the mid to late wet season when young accompany their parents in the move across the floodplains to permanent water (Frith and Davies 1961, Bayliss and Yeomans 1990, Whitehead and Tshirner 1990, Wurm 1998a, Whitehead and Dawson 2000). Dusky plains rats (*Rattus collettii*), themselves an important food resource for predators such as the water python (*Liasis fuscus*), also exploit *O. meridionalis* seed in the mid to late wet season as the water levels recede (Redhead 1979, Wurm 1998b, Madsen *et al.* 2006).

Abundant *O. meridionalis* seed is produced in the mid to late wet season, when the floodplain soils are still inundated or moist. The epidermal hooks on the awn and husk around its seeds assist their movement after dispersal through extant vegetation cover and into the inundated or wet soil. Dormancy ensures that they do not germinate in response to this initial moisture, and *O. meridionalis* populations persist only in the soil seed bank during the dry season. Eventually seed dormancy is broken and germination occurs during early wet season rains in subsequent years (Wurm 1998a).

The introduced perennial para grass (*Urochloa mutica* (Forrsk.) Nguyen) is displacing *O. meridionalis* in the Northern Territory (Wilson *et al*. 1990, Ferdinands *et al*. 2001). Para grass was introduced to the monsoonal floodplains of the Northern Territory for cattle pasture in the early 1890s (Miller and Redfern 1982, Cameron 1991, Cameron and Lemke 2002), but is now dispersed beyond grazed landscapes (Wilson *et al*. 1990, Cowie and Werner 1993, Clarkson 1995). Furthermore, the area covered by para grass is increasing. On the Magela Floodplain in the World Heritage-listed Kakadu National Park, its distribution tripled in size to cover an area of over 420 ha in the five years between 1991 and 1996, in areas which previously supported wild rice populations (Knerr 1996). Ferdinands *et al.* (2001) predicted