Field trial to test methods for eradication of fennel (*Foeniculum vulgare* Miller) on roadsides of Kangaroo Island, South Australia

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Summary

The perennial herb fennel (*Foeniculum vulgare* Miller) has been present on Kangaroo Island for approximately 50 years but has increased its range substantially in recent decades. Fennel currently infests a 7 km long section of roadside and an area of approximately 400 ha of adjacent rural lands. In 2005–06 a field trial was conducted to test a number of herbicide treatments for fennel management. The trial used glyphosate (Glyphosate 360) and triclopyr (Garlon 600) and different combinations of slashing. Pre-chemical treatment of trial plots was carried out in June 2005, chemical treatments were applied in late September 2005, and three subsequent assessments of the trial were undertaken in October 2005, February 2006 and October 2006.

In October 2005 more than half of chemically treated plants were dead or in poor condition, while fennel in untreated control plots remained unchanged. Slashing of plots prior to herbicide application resulted in 20% higher mortality rates in glyphosate treatments but no significant differences in mortality were recorded in slashed triclopyr plots. By February 2006, fennel plant mortality had increased overall in chemical treatments but only one plant died in controls. Glyphosate only treatments had significantly lower mortality than triclopyr only, triclopyr and slashing, and glyphosate and slashing treatments. Overall, slashing was more effective for glyphosate treatments than triclopyr treatments, resulting in a mortality rate 20% higher than the unslashed glyphosate treatment, whereas the difference between slashed and un-slashed triclopyr treatments was only 1.3%. Glyphosate only treatments had significantly higher resprouting rates (23%) than other treatments. Seedling emergence was observed in three glyphosate plots but not in triclopyr treatments.

In October 2006 post-treatment regeneration from resprouting and seedling germination in glyphosate treatments was significantly higher than regeneration rates in triclopyr treatments, where the response was equivalent to that in untreated controls. Few seedlings emerged in either controls or chemically treated plots over the study period, but this may have been influenced by below average rainfall in winter/spring 2006. We recommend triclopyr as the preferred chemical for fennel control on Kangaroo Island because of higher plant mortality and less post-treatment resprouting from basal corms. Fennel control should include at least two annual cycles because it is likely that some survival of herbicide treated plants will occur (resprouting) and/or seedlings will emerge. Few native plants were found adjacent to dense fennel infestations and recent surveys indicate that mostly exotic grass species are invading herbicide treated plots. Future management of treated areas will probably require restoration of native species, and other forms of intervention such as prescribed burning may prove beneficial.

Keywords: Fennel, (*Foeniculum vulgare*), herbicide field trial.

Introduction

Fennel is an erect perennial herb originating in southern Europe and western Asia (Muyt 2001). It has been used for culinary and medicinal purposes since ancient times but has spread throughout the temperate world as an invasive species and has naturalized in many agricultural areas in temperate Australia. It is widespread through New South Wales, Victoria and South Australia, especially in coastal and sub-coastal areas. It is declared noxious in Victoria, Tasmania and is under assessment in Western Australia_(Navie 2004). Fennel is not currently declared in SA but an environmental weed risk assessment for Kangaroo Island (KI) identified it as a highly invasive species in disturbed areas adjacent to intact native vegetation remnants (Pisanu 2005).

Fennel grows best in open, unshaded locations in areas of moderate rainfall with well drained, sandy soils ranging from pH 4.8 to 8.3. It is suited to disturbed areas such as roadsides, railways, drains and wasteland (Anon. 2005). Plants reproduce both vegetatively from the crown and from seed. Seed production is prolific and seed is known to persist in the soil for several years without germinating. The stems dieback partially during winter, with new leaf growth on the lower stems and crown in late winter (Parsons and Cuthbertson 2001). Dispersal is primarily by seed, which may be spread by wind, water, animals and vehicles (Blood 2003, Navie 2004).

Parsons and Cuthbertson (2001) state that spraying with an appropriate herbicide is an effective means of fennel control, best done when plants are actively growing but before flowering. Dash and Gliessman (1994) and Colvin and Gliessman (1994) trialled a number of treatments for fennel eradication on Santa Cruz Island in California. Digging and removing plants was the most effective but was impractical for large infestations. Glyphosate (as Roundup®) sprayed at the manufacturer's recommended rate (USA) in spring had a kill of up to 80%, but required repeated applications in subsequent years. Herbicide was most effective when applied to the foliage rather than cut stalks during the peak growth period (early spring). Both amine and ester formulations of triclopyr (Garlon3A® and Garlon4®) killed up to 95% of plants. In these trials, cutting of fennel did not appear to significantly increase herbicide effectiveness (Brenton and Klinger 1994).

At the time of this study there was only limited scientific information available on the treatment of fennel in Australia. Fennel is grown for commercial use in Tasmania and has become a weed in some parts of the state. The Tamar Valley Weed Strategy (Anon. 2005) lists glyphosate, dicamba, triclopyr and MCPA as herbicides registered for use on fennel. The recommendations for fennel control include slashing prior to herbicide application to promote increased leaf area, spraying in spring and the addition of a wetting agent to increase the effectiveness of glyphosate.

While fennel thrives in disturbed areas, we have observed that it does not tend to proliferate in grazed pastures or regularly cultivated paddocks. A shift in land use is occurring on Kangaroo Island with land sub-division in the area resulting in a change from sheep grazing to rural lifestyle blocks, some with absentee landholders. Land managers are concerned that, if left unchecked, fennel could eventually spread along the southern coastline of the island and seriously impact on native vegetation.

The objective of the field trial was to test methods for fennel eradication. Four treatment methods were tested, using two different chemical treatments (triclopyr and glyphosate), and slashing of some plots to remove woody material to promote foliar regrowth prior to spraying. Control plots, where no treatment was applied, were also included in the design.

Materials and methods

Study site location

Fennel infests a 7 km section of the Hog Bay Road on KI, forming a number of very dense patches on roadsides. The outer edge of the infestation is located close to Pelican Lagoon (north of Hog Bay Rd) but fennel is currently patchily distributed across about 400 ha of mostly cleared land (Latitude 137°40'46"E Longitude 35°50'0"S). The area consists of sandy soils on limestone, typical of the southern coast of the island (Robinson and Armstrong 1999). Fennel may have been present for as long as 50 years but the first herbarium collection was made in June 1985, when the population was estimated to be around 30 plants. By 1992 fennel was abundant along a 5 km stretch of Hog Bay Rd, and the population is estimated to have quadrupled in the last 10 years.

Field trial design and methods

The experiment was a randomized block design, used to ensure each experimental treatment and the controls were replicated over all of the area being sampled, therefore reducing bias linked to background variation (Underwood 1997). All treatments were represented in each block but there was no replication of treatments within blocks. Treatments within each block were allocated randomly. Experimental blocks consisted of contiguous 10 m × 3 m plots, marked out with wooden stakes along top and bottom edges and separated by stringlines. Two blocks, 20 m apart, are located on the northern edge of Hog Bay Rd in a dense infestation of fennel. The third block is on the southern side of the road. Twenty fennel plants were assessed in each plot. Plants were tagged with an aluminium tag and marked with a code for block, treatment and sample number. (Figure 1).

Plots used in the chemical and slashing treatments (T3 and T4) were slashed on 20th June 2005. The tops of plants were removed to a height of approximately 0.5 m and slashed material was removed from plots. Chemical herbicide treatments of fennel plots were undertaken on September 19th and 20th 2005. Slashed plants had resprouted from their crowns, producing regrowth approximately 10 to 20 cm in height. New growth was dark green indicating plants were not stressed. Most plants were flowering, especially in un-slashed plots. Two readily available and widely used herbicides were used in the KI trial. Glyphosate (Glyphosate 360, Brunnings) as an isopropylamine salt, and an ester form (triclopyr butoxyethyl ester) of tricolpyr (Garlon 600, Dow AgroSciences). Herbicide was applied using a hand spray unit at dosages based on manufacturers' specifications. Garlon 600 was mixed at a rate of 20 mL per 5.5 L, and a non-ionic wetting agent/spreader (Pulse, Nufarm) was added at 20 mL per 5.5 L and a dye (Redeye, CropCare) was used to colour the solution. No specifications for fennel were available for Glyphosate 360 (Brunnings). For the trial, a dose of 30 mL per 5.5 L was used with 20 mL per 5.5 L of wetting agent and red dye to colour.

All native and exotic species found in trial plots were recorded to allow for evaluation of the post-treatment response in native vegetation and invasive weed species (Table 1). The first survey to measure the results of chemical applications was undertaken on October 26th, 2005. Plant condition was assessed for tagged plants in each treatment. Plants were classified as alive (no effect), poor (up to 90% of foliage dead), very poor (<10% live material), or dead (no live material). A second survey on 14th February 2006 was conducted to determine if plants had recovered from the effects of chemical treatments in October 2005, and to record total plant mortality. Survey methods were the same as applied previously, but individual plants were assessed differently. If new growth was observed this was classified as either major resprouting (≥0.5 m height) or minor resprouting (<0.5 m height).

A statistical analysis was undertaken to compare the mortality of plants in chemically treated plots with the controls using one-way analysis of variance (ANOVA). All means were compared for different levels of treatment using the Tukey-Kramer HSD multiple comparison test. Count data were transformed prior to analysis using a square-root function to re-scale variables to meet assumptions of normality (Sokal and Rohlf 1995; Underwood 1997). ANOVA was also used to compare rates of resprouting from basal corms and to test for differences in fennel seedling emergence in treatments and controls.

Field trial results

Fennel infested plots supported very few native plants at the beginning of the trial and this pattern was observed to be common on roadsides, except in areas with rocky ground, such as adjacent to road cuttings, which had less fennel and more native cover. The weed *Asparagus asparagoides* (bridal creeper) was common in Blocks 1 and 2, and a total of five native plant species were found in or on the edge of trial plots (Table 1).

The first assessment of the fennel trial in October 2005 showed that glyphosate had a more immediate impact on the condition of fennel plants. Thirty-six percent of plants in Treatment 2, and 47% in Treatment 4 appeared to be dead and the remainder were mostly in very poor condition. In contrast, application of triclopyr resulted in very few immediate plant deaths, but most plants in the trial were in poor condition (56% in Treatment 1 and 100% in Treatment 3). These plants appeared to be in an intermediate state of decline. Clear differences between control plots (C) and chemically treated plots were apparent because few fennel plants died in the control plots over the survey period (Table 2).

By February 2006, only one plant had died in a control plot. In contrast, in experimental treatments between 46 and 59 out of 60 plants (76.7–98.3%) were dead with no signs of regrowth. Plants in glyphosate only treatments (T1) resprouted at a higher rate (23%) than glyphosate treatments that were slashed (T4) (3.3%). Both types of triclopyr treatments (T2 and T4) had low resprouting (3.3%). The proportion of plants classified as having major resprouting was also higher overall in glyphosate treatments (Table 3).

The results for fennel mortality show that there was a significant difference between controls (low mortality) and all chemical treatments, where higher plant mortality occurred (Table 4). The comparison of means for different chemical treatments indicates that mortality in T2

Figure 1. Fennel field trail experimental design: 3 × blocks, each with 4 × treatments + 1 control (randomly allocated). Treatment 1 (T1): triclopyr only; Treatment 2 (T2): glyphosate only; Treatment 3 (T3): triclopyr + slashing; Treatment 4 (T4): glyphosate + slashing; Control (C): no treatment applied.

BLOCK 1

T1	T2	T4	T3	C

BLOCK 2

T4	T1	T3	T2	C

BLOCK 3

T3	C	T4	T1	T2

Table 1. Native plants and weeds found in fennel trial plots.

Species name	Common name	Block/treatment
Acaena novae-zelandiae	bidgee-widgee	B3-T1, B3-T2, B1-T2
**Asparagus asparagoides*	bridal creeper	B1-T2, B1-T4, B1-T3, B1-C, B2-T4, B2-T1, B2-T2
Leucopogon parviflorus	coastal bearded-heath	B3-T3
Tetragonia implexicoma	bower spinach	B1-T1, B1-T2
Olearia axillaris	coast daisy-bush	B3-T2
Pimelea serpyllifolia	thyme riceflower	B3-T4, B3-T1

* introduced species.

(glyphosate only) was significantly lower than in T1 (triclopyr only), T3 (triclopyr + slashing) and T4 (glyphosate + slashing) (Table 5). A comparison of resprouting rates showed resprouting in T2 (glyphosate only) was significantly higher than in other treatments (T1, T3 and T4) and control plots, where resprouting rates were comparatively low (Table 5).

The October 2006 survey determined if fennel in chemical treatments regenerated from resprouting or seedling recruitment during the 2006 winter rainfall period. More resprouting plants and seedlings were recorded in glyphosate treated plots (T2 and T4) than in triclopyr plots (T1 and T3) and controls (C) (Figure 2). Significant differences existed at the treatment level (Table 4). A comparison of means test showed that glyphosate treatments (T2 and T4) had significantly higher resprouting rates than triclopyr treatments (T1 and T3). In fact triclopyr treatments had equivalent resprouting to the untreated controls (Table 5). Seedling regeneration between treatments was not significantly different (Table 4). Generally, few seedlings emerged in either controls or chemically treated plots.

A number of plants, mostly exotic grass species, were observed in plots from which fennel had been removed (Table 6). The density of different species was not measured but these new invasive species appeared to be well established and collectively provided a high level of cover.

Discussion and management recommendations

The early results of the trial in February 2005 indicated that glyphosate was more effective than triclopyr, but by October 2006 fennel mortality rates in triclopyr plots were equivalent, however, glyphosate was most effective on plants that had been slashed prior to chemical treatment. Slashing made no difference to the efficiency of triclopyr, similar to the results obtained on Santa Cruz Island, where cutting prior to application of this herbicide did not result in significant differences in plant mortality (Brenton and Klinger 2002). One advantage of slashing noted by land managers in the KI trial is that it allowed for better access to dense infestations when hand spraying was used.

A disadvantage from the application of glyphosate was that plant resprouting rates were higher in all glyphosate treatments, and regrowth from crowns in these treatments was observed to be well developed and vigorous. This indicates that follow up spraying would be required to ensure complete eradication of fennel. Again, a result similar to that obtained for fennel control on Santa Cruz Island (Dash and Gliessman 1994, Colvin and Gliessman 1994). Also, there were signs of seedling emergence in a number of glyphosate plots, but none was observed in plots treated with triclopyr, increasing the requirement for follow up spraying to exhaust the soil seed bank if glyphosate is used. It should be emphasized that rainfall in winter/spring 2006 was lower than average and poor germination may be linked to this. It is plausible that higher rainfall could increase the seedling germination response in experimental treatments.

The fact that almost all new plants germinating in chemically controlled trial

Table 2. Summary of fennel responses to chemical/slashing treatments, October 2005 survey. Data pooled from three treatment blocks. Data = count (percentage). Classes: dead (no live material), very poor (<10% live material), poor (up to 90% foliage dead), alive (no effect).

Treatment	Application	Dead	Very poor	Poor	Alive
T1	Triclopyr only	4 (6.6)	0	56 (93.4)	0
T2	Glyphosate only	36 (60)	22 (36.7)	36 (60)	0
T3	Triclopyr + slashing	0	0	60 (100)	0
T4	Glyphosate + slashing	47 (78.3)	10 (16.7)	3 (5)	0
Control	No treatment applied	1 (1.7)	0	0	59 (58.8)

Table 3. Summary of results for February 2006 surveys. Minor R= minor resprouting (stems ≤0.5 m height); Major R = major resprouting (stems >0.5 m). Data pooled from three experimental blocks. Data = count (percentage).

Treatment	Application	Dead	Minor R	Major R	Alive
T1	Triclopyr only	58 (96.7)	0	2 (3.3)	2 (3.3)
T2	Glyphosate only	46 (76.7)	3 (5)	11 (18.3)	14 (23.3)
T3	Triclopyr + slashing	59 (98.3)	1 (1.7)	0	1 (1.7)
T4	Glyphosate + slashing	58 (96.7)	0	2 (3.3)	2 (3.3)
Control	No treatment applied	1 (1.7)	0	0	59 (98.3)

Table 4. ANOVA results for plant mortality, resprouting from basal corms and seedling germination at the treatment level. Results shown for October 2005 and October 2006 surveys.

Source	Mean square	d.f.	F-ratio	Prob>F
Plant mortality (2005)	7.33	4	305.64	<0.0001*
Resprouting (2005)	1.16	4	12.94	0.0006*
Resprouting (2006)	2.30	4	7.34	0.005*
Seedlings (2006)	3.77	4	0.56	0.695^{NS}

* Significant at 95% confidence level; NS not significant.

Table 5. Means comparisons for all pairs, Tukey-Kramer HSD; treatments = plant mortality, resprouting 2005 and 2006. Treatment levels not connected by the same letter are significantly different.

Source	Treatment				Mean
Plant mortality (2005)	T3	A			4.49
	T4	A			4.45
	T1	A			4.45
	T2		B		3.98
	Control			C	0.88
Basal resprouting (2005)	T2	A			2.27
	T4		B		1.05
	T1		B		0.99
	T3		B		0.88
	Control		B		0.71
Basal resprouting (2006)	T2	A			2.83
	T4	A	B		2.24
	T1	A	B	C	1.35
	T3		B	C	1.05
	Control			C	0.71

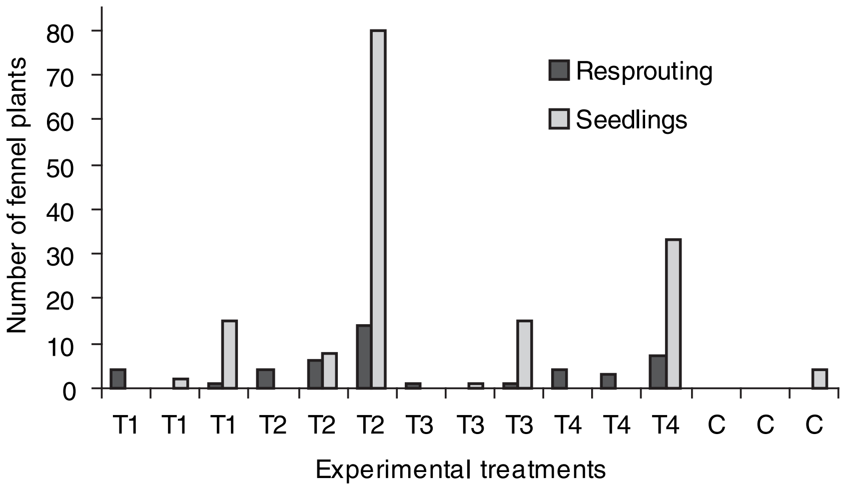

Figure 2. Fennel regeneration response – October 2006. Total numbers of seedlings and resprouting plants within experimental plots.

Table 6. Plant species observed in fennel control plots in October 2006.

Scientific name	Common name	Status
Aspodelus fistulosus	onion weed	weed
Austrostipa species	spear grass	native
Avena species	oat grass	weed
Briza minor	shivery grass	weed
Bromus madritensis	Madrid brome	weed
Lagurus ovata	hare's-tail grass	weed
Lolium perenne	rye grass	weed
Vulpia species	fescue grass	weed

plots were weeds (primarily grasses) suggests they may compete effectively against the establishment of native plants, such as *Acaena novae-zelandiae* (bidgee-widgee) and *Leucopogon parviflorus* (coastal bearded-heath), that were recorded on the edge of plots at the beginning of the study. This reinforces the need for follow-up weed control and replanting of native species if deemed necessary. In a study of native vegetation recovery on Santa Cruz Island, Erskine Ogden and Rejmánek (2005) found that non-native grasses replaced fennel over time and that native plant recovery in treated plots was generally poor.

Planning for large-scale control of fennel should include consideration of the likelihood that roadside sites will be re-invaded from adjacent dense infestations of fennel. We recommend at least a 20 m wide roadside strip be treated and, where feasible, control is extended to adjacent areas. Changes in land use resulting in cessation of sheep grazing are likely to result in expansion of fennel because grazing pressure is reduced. This response to changed land use has been documented for Santa Cruz Island (Brenton and Klinger 2002). Fennel control should include at least two annual cycles because it is likely that some survival of herbicide treated plants will occur and/or seedlings will emerge from the dormant seedbank. Brenton and Klinger (2002) suggest burning may be a useful control technique for fennel, although this has not been tested experimentally. On KI, an approach that combines prescribed burning to reduce fennel regeneration and promote germination of native plants from soil seedbanks, and supplementary planting may ultimately be required to ensure fennel is controlled over the long term.

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