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Herbicide screening trial to control dormant wilding *Pinus contorta*, *P. mugo* and *Pseudotsuga menziesii* during winter.

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Abstract

In New Zealand, wilding conifers threaten over 210 000 hectares of land administered by the Department of Conservation in the South Island alone. Currently, the contact herbicide diquat is applied aerially at a rate of 15 L/ha in 400 L of water to control *Pinus contorta* (Dougl.). As this treatment is not very effective, and has an adverse effect on non-target species, the objective of this study was to evaluate if there are more effective alternative herbicide treatments to control not only *P. contorta*, but also *Pinus mugo* (Turra) and *Pseudotsuga menziesii* (Mirb.) Franco.

The currently operational herbicide diquat treatment was compared with a second diquat-only treatment at the same 15 L/ha rate but applied in 150 L total volume. Seven treatments using alternative herbicides were also studied. All treatments were applied during winter in a pot-based trial.

Analysis of variance showed highly significant differences between herbicide treatments ($F_{8,32}$ = 53.3, p<0.0001), between species ($F_{2,72}$ = 71.8, p<0.0001) and also detected a significant interaction between species and treatment ($F_{16,72}$ = 9.8, p<0.0001). When averaged across all treatments, damage to *Pinus contorta* and *Pseudotsuga menziesii* was 84%, which significantly exceeded that to *Pinus mugo*, at 68%. Due to the significant interaction, each species was also analysed individually.

Overall, the most effective treatment contained two selective systemic herbicides, triclopyr, and picloram, which caused a minimum of 98% damage for all species. Results indicate that treatments containing the non-selective systemic herbicide glyphosate controlled *Pinus contorta* and *Pseudotsuga menziesii* very effectively. *Pinus mugo*, however, was only moderately affected by these treatments. Treatments containing diquat were generally more effective than those containg glyphosate but less effective than treatments containing triclopyr/picloram.

Keywords: herbicides; pot trial; wilding conifers.

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Introduction

Dense infestations of wilding *Pinus contorta* (Dougl.), *P. mugo* (Turra) and *Pseudotsuga menziesii* (Mirb.) Franco are a major weed problem in grass and shrubland ecosystems in the New Zealand high country (Paul & Ledgard, 2008; Ledgard, 2001). These wilding conifers are pioneer species that invade, and adversely affect, a wide variety of sites and threaten thousands of hectares of land on both the North and South Island of New Zealand (Harding, 2001; Ledgard, 2001; Crozier, 1990; Hunter & Douglas, 1988). According to Ledgard (2003), the area that could potentially be infested by exotic conifers is likely to be more than 300 000 hectares in the South Island alone.

In New Zealand, the Department of Conservation (DOC) is required by legislation under the Reserves Act 1977, National Parks Act 1980, and Conservation Act 1987 to control these wilding conifers on the land it administers. Inadequate control at an early stage can lead to an escalation of costs from $500/ha to as much as $6000/ha (G. Miller, DOC, pers. comm., September 2008). The Department of Conservation and various other landowners are attempting to control, and if possible eradicate, wilding conifers on both conservation and private land.

Historically, control of *Pinus contorta* has been successfully achieved using the contact herbicide diquat (6,7-dihydrodipyrido[1,2-a:2',1'-c] pyrazinediium dibromide) followed by burning (Ray & Davenhill, 1991). The combination of herbicide treatment and fire resulted in very effective wilding conifer control, because the subsequent fire killed most surviving trees and viable seed. However, burning is no longer an acceptable management practice on DOC-administered land. The current practice of spraying with a mixture of diquat herbicide and an adjuvant, such as the surfactant wetting agent Pulse™ (Monsanto Ltd, Australia) is ineffective at controlling large and dense infestations of most wilding conifers (P. A. Raal, L. Huggins & G Miller unpublished Department of Conservation report, 2008; Crozier, 1990; Gratkowski, 1975).

Ray and Davenhill (1991) screened 22 herbicide treatments for control of *Pinus contorta*. They found that of the three most effective treatments, diquat applied at 1.4 kg/ha mixed with polyalkyleneoxide-modified heptamethyltrisiloxane wetting agent (Silwet L77, GE Silicones; 0.5%) had the most desirable effect (i.e. least damage to other ground cover and produced the most rapid damage to pine foliage). However, the range of herbicide rates they studied was limited and was adjusted to a cost of approximately $100/ha. Cost was not a constraint in the current project.

To ensure maximum herbicide efficacy, foliar treatment should be undertaken when pines are actively growing during summer i.e. December to February (P. A. Raal unpublished Department of Conservation report, 2005). However, many regions with wilding problems are located at high altitude in dryland areas east of the main axial ranges. These regions suffer from seasonal water deficits and cold conditions during summer. As a consequence, pines are not always actively growing during the time of herbicide application. The aim of this study was to simulate the sub-optimal uptake of herbicides during periods of low growth and identify the baseline effect of these herbicides. This was done by applying herbicides to dormant trees during mid-winter in Rotorua. Rotorua is in the central North Island and has a cold-winter climate.

This study also investigated the efficacy of potential alternative herbicide treatments for the control of wilding conifers. The alternative treatments trialled can be categorised into two groups:

1. herbicides using primarily Glyphosate 360® (which contains a non-selective systemic herbicide glyphosate [N-(phosphonomethyl)glycine]. These treatments can be used on dense conifer infestations, where non-target species are not at risk; and

2. herbicides based on a formulation of Tordon® (containing two selective systemic herbicides, triclopyr [(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid and picloram (4-amino-3,5,6-trichloropicolinic acid)). The triclopyr/picloram formulations are intended for use in areas where non-target native monocotyledon vegetation is present.

The systemic mode of action of these alternative formulations contrasts with the current operationally applied Reglone® which contains diquat, a contact herbicide.

Materials and Methods

Two hundred and fifty 300-mm high seedlings each of *Pinus contorta* (Ferintosh Station, near Twizel), *P. mugo* (Muddy Creek near Wanaka) and *Pseudotsuga menziesii* (Ribbonwood Station near Twizel) were collected in the field and transplanted into five litre plastic pots, six months prior to treatment. All trees were irrigated as required and kept under 60% shade for the first three months, then placed outside to harden-off prior to treatment.

Twenty-five healthy trees of each species were divided into five replications of five trees each in a randomised complete block design to test nine herbicide treatments. Details of each treatment are shown in Table 1. An untreated control was also included in the experiment. During the first week of July 2008, each of the nine herbicide treatments was applied using a calibrated boom sprayer, fitted with Turbo Teejet

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TABLE 1: Herbicide treatments for the wilding conifer pot trial.

Treat-ment no.	Product used	Product type	Manufacturer	Active ingredient	Spray volume (L/ha)	Active ingredient (g/L)
1	15 L Reglone	Contact herbicide	Syngenta Crop Protection Ltd	Diquat dibromide monohydrate, 200 g/L	400	7.5
	1.5 L Pulse	Wetting agent	Nufarm Ltd	Organo-modified polydimethylsiloxane, 80%		3
2	15 L Reglone	Contact herbicide	Syngenta Crop Protection Ltd	Diquat dibromide monohydrate, 200 g/L	150	20
	1.5 L Pulse	Wetting agent	Nufarm Ltd	Organomodified polydimethylsiloxane, 80%		8
3	15 L Glyphosate 360	Non-specific systemic herbicide	AGPRO NZ Ltd	*N*-(phosphonomethyl)glycine, 360g/L	150	36
	1.5 L Pulse	Wetting agent	Nufarm Ltd			8
4	15 L Glyphosate 360	Non-specific systemic herbicide	AGPRO NZ Ltd	*N*-(phosphonomethyl)glycine, 360g/L	150	36
	50 g Escort	Selective systemic herbicide	Du Pont (NZ) Ltd	Methyl 2-(4-methoxy-6-methyl-1,3,5-triazin-2-ylcarbamoylsulfamoyl)benzoate, 30 g		0.2
	1.5 L Pulse	Wetting agent	Nufarm Ltd	Organomodified polydimethylsiloxane, 80%		8
5	15 L Glyphosate 360	Non-specific systemic herbicide	AGPRO NZ Ltd	*N*-(phosphonomethyl)glycine, 360g/L	150	36
	150 g Escort	Selective systemic herbicide	Du Pont (NZ) Ltd	Methyl 2-(4-methoxy-6-methyl-1,3,5-triazin-2-ylcarbamoylsulfamoyl)benzoate, 90 g		0.6
	1.5 L Pulse	Wetting agent	Nufarm Ltd	Organomodified polydimethylsiloxane, 80%		8
6	15 L Glyphosate 360	Non-specific systemic herbicide	AGPRO NZ Ltd	*N*-(phosphonomethyl)glycine, 360g/L	150	36
	1.5 L Reglone	Contact herbicide	Syngenta Crop Protection Ltd	Diquat dibromide monohydrate, 200 g/L		20
	1.5 L Pulse	Wetting agent	Nufarm Ltd	Organomodified polydimethylsiloxane, 80%		8
7	20 L Glyphosate 360	Non-specific systemic herbicide	AGPRO NZ Ltd	*N*-(phosphonomethyl)glycine, 360g/L	150	72
	1.5 L Pulse	Wetting agent	Nufarm Ltd	Organomodified polydimethylsiloxane, 80%		8
8	15 L Trichloram Brush-killer	Selective systemic herbicide	AGPRO NZ Ltd	{[(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid}, 300 g/L + 4-Amino-3,5,6-trichloropicolinic acid (Picloram), 100 g/L	150	30 10
	1.5 L Pulse	Wetting agent		Organomodified polydimethylsiloxane, 80%		8
9	20 L Trichloram Brushkiller	Selective systemic herbicide	AGPRO NZ Ltd	{[(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid}, 300 g/L + 4-Amino-3,5,6-trichloropicolinic acid (Picloram), 100 g/L	150	40 13.33
	1.5 L Pulse	Wetting agent		Organomodified polydimethylsiloxane, 80%		8
10	Control	None	-	None	0	-

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Induction nozzles (TTI 02) (Spraying Systems Co. Wheaton, Illinois, USA) at a pressure of 200 kPa, at a height of 0.5 m above the seedling canopy. These nozzles produced a spray characterised by droplets with a volume mean diameter (VMD) greater than 500 μm.

Percentage damage to the foliage of the trees was visually recorded in increments of 10%, by the same assessor for the duration of the trial. Assessments were undertaken prior to treatment and post treatment at monthly intervals, to a maximum of 267 days after the treatments were applied. A tree with no damage was given a score of 0% and a tree that died was given a score of 100%.

An analysis of variance was used to test the main and interactive effects of herbicide and species on foliar damage, at the end of the experiment, 267 days after the treatment was applied (SAS, 2004). In this model, block and the interaction of block and treatment were included as random terms. The analysis of variance excluded the untreated control to ensure that the test was sensitive to variation between herbicide treatments, rather than the considerable difference between all the herbicide treatments and the untreated control. The untreated control was included for the multiple range tests, to provide a full comparison of all treatments.

Results and Discussion

The analysis of variance showed highly significant differences between herbicide treatments ($F_{8,32}$ = 53.3, p<0.0001), between species ($F_{2,72}$ = 71.8, p<0.0001) and also detected a significant interaction between species and treatment ($F_{16,72}$ = 9.8, p<0.0001). When averaged across all treatments damage for *Pinus contorta* and *Pseudotsuga menziesii* was 84%, which significantly exceeded that of *Pinus mugo*, at 68%. Due to the significant interaction between species and treatments, each species was subsequently analysed separately (Table 2). These results indicate that *Pinus mugo* will be more difficult to control than either *Pinus contorta* and *Pseudotsuga menziesii.*

Damage from treatments containing only the contact herbicide diquat (Treatments 1 and 2) were visible within one to two months after application (Figure 1). In contrast, treatments containing predominantly systemic herbicides took about three months to show similar visual effects (Figure 1).

Treatment 9 (triclopyr/picloram applied at the equivalent of 20 L/ha) caused the highest level of damage after 267 days, averaging 99% across species, and causing at least 98% damage for all three species (Figure 1).

Treatment 8 (triclopyr/picloram applied at the equivalent of 15 L/ha) was expected to be the next most

TABLE 2: Mean damage and standard errors, by treatment and species, 267 days after application of the treatment, for *Pinus contorta*, *Pseudotsuga mensiesii* and *Pinus mugo*. Means followed by the same letter are not significantly different at p<0.05. For the analysis of variance *F*-values are shown, followed by the *p*-categories. Asterisks *** represent significance at p<0.001.

Treatment	Mean damage (percentage)					
	Pinus contorta		*Pseudotsuga mensiesii*		*Pinus mugo*	
	Mean	S.E.	Mean	S.E.	Mean	S.E.
1	100	0 a	96	4.0 a	98	1.6 a
2	100	0 a	98	2.4 a	90	5.7 a
3	100	0 a	98	1.5 a	87	2.8 a
4	100	0 a	100	0 a	86	4.2 a
5	98	1.6 a	100	0 a	73	9.8 b
6	51	6.5 b	64	7.8 b	41	4.5 c
7	100	0 a	100	0 a	79	7.7 b
8	95	2.1 a	68	7.3 b	27	4.0 c
9	100	0 a	98	1.6 a	100	0 a
10	0	0 c	11	7.9 c	0	0 d
Significance of one way ANOVA						
Treatment	14.6***		46.6***		22.1***	

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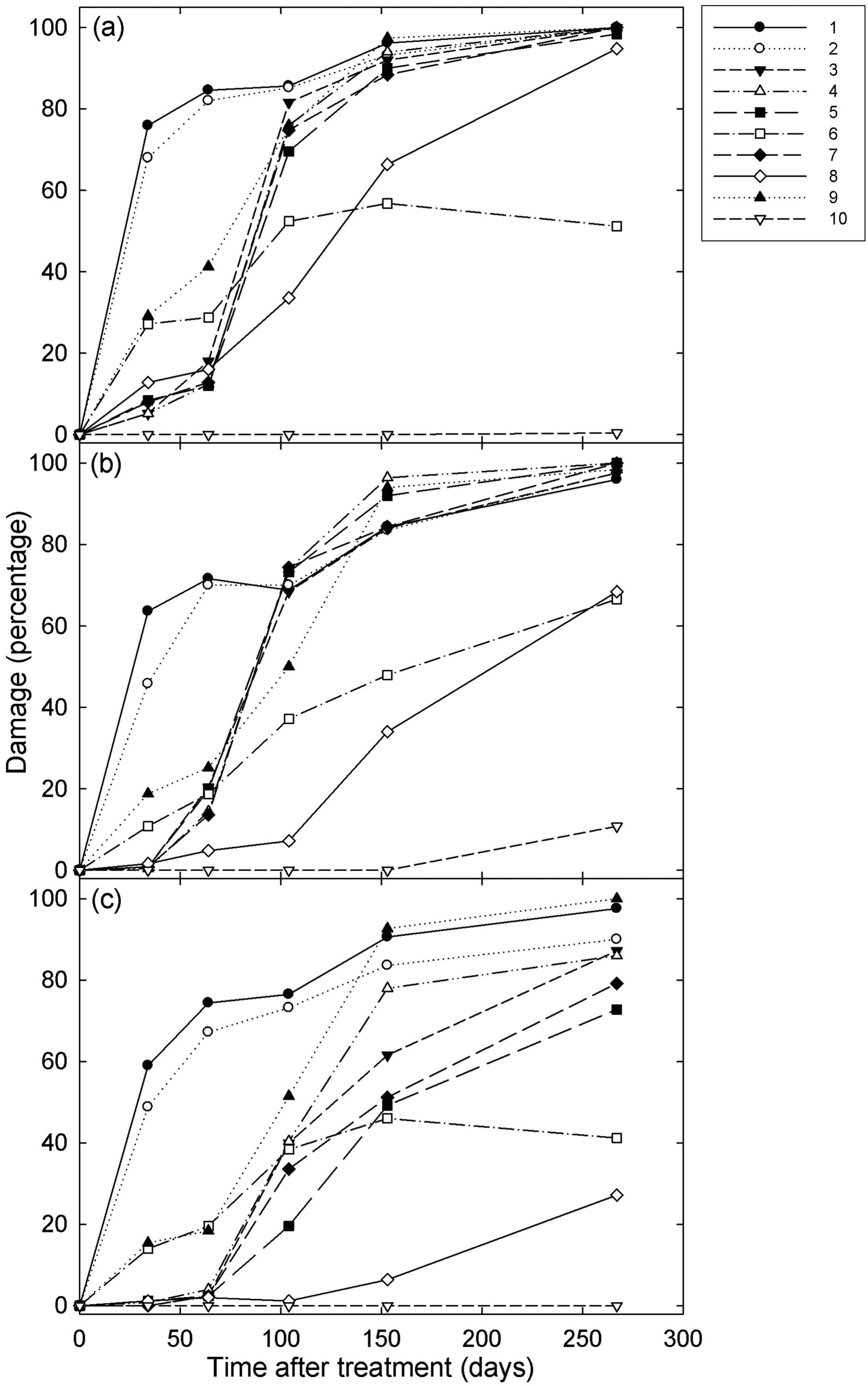

FIGURE 1: Changes in damage with time, by treatment for: (a) *Pinus contorta;* (b) *Pseudotsuga menziesii;* and (c) *Pinus mugo*. Treatments shown in the figure legend follow the numbering system of Table 1.

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effective treatment. However, heavy rain fell for more than 30 minutes less than two hours after applying this treatment. The precipitation was well within the period (3 h) required before the treatment was rain-fast and, therefore, can explain the low damage that was observed in this case.

Treatments 1 and 2 were the next most effective overall. These both contained the same amount of only one herbicide, diquat. The difference between these two treatments was the application volume. Diquat was applied at an operational rate of 3 kg in 400 L water in Treatment 1 and at 3 kg in 150 L water in Treatment 2. On average, Treatment 1 caused 98% damage while Treatment 2 caused 96% damage. Reducing the application volume of the diquat treatment from 400 L/ha to 150 L/ha did not significantly reduce efficacy of the herbicide. It is possible that the relatively similar efficacy of Treatments 1 and 2 was attributable to a trade-off between a lower application rate (reduced coverage) and higher herbicide/adjuvant concentration.

Although both treatments containing only diquat were very successful at controlling wilding trees in this pot trial, operational applications in the field have shown this treatment to have somewhat reduced efficacy (P. A. Raal, L. Huggins & G Miller unpublished Department of Conservation report, 2008; Crozier, 1990; Gratkowski, 1975). This disparity may be attributable to the greater density and size of trees in the field compared with the small trees studied here. High density reduces herbicide penetration into the crown, and large tree size reduces the impact of the herbicide. Under operational applications, large droplets (VMD > 450 μm) are used to minimise potential drift. Using this size droplet to apply a contact herbicide such as diquat is likely to result in insufficient spray coverage, reducing the total defoliation that is required to kill dense wilding stands (Moorhead, 1998; Ledgard & Norton, 2008).

Four treatments contained glyphosate either as the sole active ingredient (Treatments 3 and 7) or in combination with another systemic herbicide metsulfuron methyl, methyl α-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]amino]sulfonyl] benzoate, Escort® (Treatments 4 and 5). Metsulfuron is the most frequently used herbicide treatment in commercial forestry land preparation. Uptake of metsulfuron is from the soil whereas uptake of glyphosate is from foliage. A treatment containing both these systemic herbicides controls a broader spectrum of weed species than each herbicide alone. All four of these treatments were highly effective against both *Pinus contorta* and *Pseudotsuga menziesii* causing a minimum of 98% damage. However, these four treatments were less effective against *Pinus mugo*. Damage to this species ranged from 73% for Treatment 5 to 87% for Treatment 3.

Treatment 6, which contained a combination of glyphosate and diquat, was the least effective treatment, with damage averaging 52% across the three species. This low level of damage is consistent with our understanding of herbicide mode-of-action. The systemic herbicide, Glyphosate is absorbed by foliar parts of a plant and then translocated within the plant system to tissues that may be remote from the point of application. In contrast, the contact herbicide, Diquat disrupts cell membranes and very rapidly kills plant tissue (Ross & Childs, 1994), which, in turn, reduces uptake and translocation of the glyphosate into the plant. Therefore, we consider that that adding diquat to glyphosate has an overall antagonistic effect.

Further Research

Further research should investigate the effectiveness of lowering spray volume for systemic herbicide treatments in operational trials. Lowering total application volume can vastly increase aircraft productivity and, therefore, greatly reduce application costs. As systemic herbicides are translocated through the plant, the potentially low coverage resulting from low rates is unlikely to markedly reduce efficacy.

Further research should also be undertaken to determine how variation in adjuvant concentration affects uptake and efficacy of diquat.

Conclusions

Pinus contorta and *Pseudotsuga menziesii* were significantly more susceptible to the herbicides tested than *Pinus mugo*. Efficacy varied significantly between herbicides. The results indicate that the triclopyr/picloram treatment (applied as Tordon® at 20 L/ha; Treatment 9) was more effective than either of the two diquat-only treatments tested. These, in turn, were more effective than any of the glyphosate-based treatments. This suggests that Treatment 9 may be a suitable alternative to the operational diquat treatment for all three tree species tested.

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